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Development of Efficient Frequency and Sensitivity of Transducer on Flaw Measurement by Using Ultrasonic Testing Method on Thin Carbon Steel Plate

Muhammad Adam Baduhalin[1], Abdul Syahmie Azri Abdul Rani[2], Jeffry Jamil[1], Muhammad Nur Farhan Saniman[3], Eliza M. Yusup[1]*

[1] *Centre for NDT Training and Calibration (CeNDTeC), Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, MALAYSIA*
[2] *Project Management Unit, Brooke Dockyard and Engineering Works Corporation, Jalan Bako, Kampung Sejingkat, 93050 Kuching, Sarawak, MALAYSIA*
[3] *Mechanical Engineering Section, Malaysia France Institute, Universiti Kuala Lumpur, 43650 Bandar Baru Bangi, Selangor, MALAYSIA*

*Corresponding Author: elizay@uthm.edu.my
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Ultrasonic Testing Flaw Detector (UTFD), Non-Destructive Testing (NDT), transducer, beam spread

Abstract

Throughout several decades, welded pipes has been some of the critical areas that required scheduled inspection. The Ultrasonic Testing Flaw Detector (UTFD) method of Non-Destructive Testing (NDT) is one of the reliable technologies for early detection of any internal flaw that would present an impressive danger. The objective of the research is to determine the selection of transducer in detecting defect at Carbon Steel sample with single Vee butt joint. The experimental work in this study is using two different frequencies of transducer, which are 2MHz and 4Mhz. Each of the transducer represent by three different angles, which are 45°, 60° and 70°. The sample with thickness, t = 12mm is inspected with several types of scanning movement including depth, swivel, orbital and lateral scanning. Another parameter involves is different sensitivity of the transducer by controlling the gain of the machine. From the observation of the results, the sensitivity is directly proportional to the angle of the transducer, where for 4MHz, the readings for gain at 45°, 60° and 70° angles are 43.30 dB, 47.50 dB and 48.30 dB, respectively. At the end, it can be concluded that 4MHz transducer with 60° angle provide the most accurate measurement of flaw detector compared with other angles. Furthermore, this research also shows that when the frequency is increased, it produces shorter wavelength and better resolution with shorter beam spread compared to low frequency transducer.

1. Introduction

Welded pipe joints are basic segments in offshore structures, extensions, and huge range rooftop structures, for which the weariness actuated splits present impressive dangers. Besides, solid measuring of breaks along these lines becomes fundamental in the trustworthiness and abused life appraisal of these structures [1]. Non-Destructive Techniques (NDTs) through Ultrasonic Testing (UT), give helpful intent to screen and examine the states of a wide scope of structures, systems, or equipment [2].

The ultrasonic staged exhibit notable for its convenience, dependability, and generally high exactness, still cannot seem to discover wide applications in welded pipe joints, which involve an unpredictable geography of discontinuity [3].

The UT inspection method for NDT is based on the transmission of short wavelength, high frequency mechanical waves from a probe and detection by the same or other probes [4]. The time it takes for an ultrasonic pulse to travel to a reflector (a flaw, the rear surface, or another free surface) is displayed on the associated oscilloscope display with a time base. Indicates the distance travelled across the oscilloscope screen in terms of the time it takes an ultrasonic pulse to travel to a reflector (a flaw, the back surface, or another free surface) [5]. The fault size as observed from the transmitter probe is related to the height of the reflected pulse. The relationship between discontinuity size, distance, and reflectivity is complicated, and it takes a lot of skill to analyze the data from UT machine.

Of many types of NDTs, UT mechanism involves sound wave as their main component to detect any foreign material or discontinuity in the welding area or Heat Affected Zone (HAZ) of the parent material [6]. Sound wave can propagate in a various type of modes that considerable when using UT method to search any discontinuity. There is a compression wave, shear wave, surface wave and plate wave. Compression wave and shear wave are the most common waves applied in UT method [7]. It involves respectively on zero-degree probe and angle probe where these waves also require acoustical media to let the sound travel efficiently especially on solid media compared to liquid and gas media that worked less efficiently [1].

The primary factor influencing component performance is friction, which results in resistance between any two moving surfaces and the beginning of component wear [8]. Due to their restricted access to management and business technology like Six Sigma, small businesses confront a few difficulties. Their biggest obstacles are, among others, problems with product flaws, consumer complaints, poor product quality, ineffective work management, and concerns with personnel management [9].

So, in this circumstances author is focusing on product flaws where UT can detect any flaws located on the sub-surface and internal of welding area and parental material. From industrial practical there are many types of flaws such as crack, slag inclusion, porosity, lack of weld fusion and others [10]. Without destroying the equipment or specimen, UT is the most efficient among other conventional methods to specify the detail of flaw in the welded area and HAZ area of the material tested [11]. The detail includes determination of types of flaws, height, depth, and length. UT has exhibited accomplishment in the recognition of defects, thickness, and welding investigation [12]. Fig. 1 shows an example of flaw detection on the UT machine display screen.

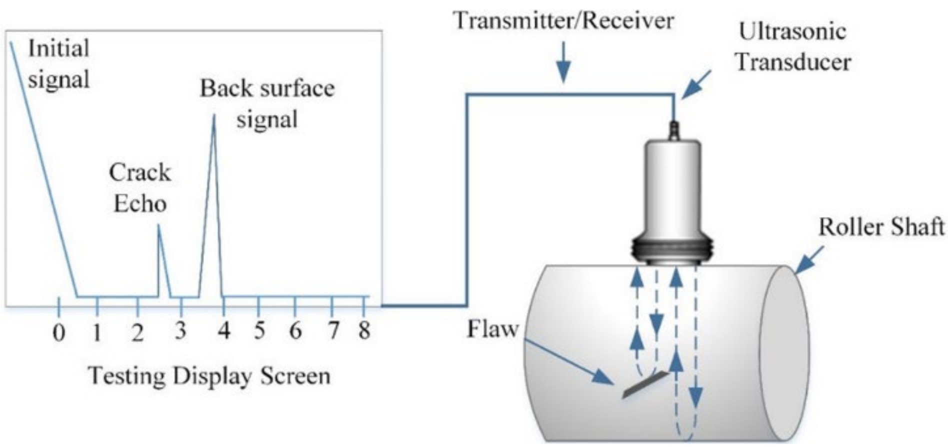


Fig. 1 *Crack echo shown on the UT machine display screen [13]*

2. Methodology

A carbon steel plate with single vee butt weld is used as the sample for the research, as detailed in Table 1. The inspection was implemented with conventional UT testing machine, model Rigor RFD 60, manufactured company is Rigor Tech. The testing machine is set based on the given guidelines for ultrasonic testing of various materials in American Standard Mechanical Engineering (ASME), Section V, Article 5 [14]. It includes the setting of velocity based on the tested material as shown in Fig 2, thickness of the sample and other important setting. The testing on the test specimen proceeds once the setting on the testing machine is completed. This step is important and required each time prior to testing. The reason is to ensure that the obtained data gathered from the machine are valid and reliable.

Table 1 *Details of test specimen*

Data	Description
Material of Test Specimen	Carbon Steel
Serial Number	141368
Type of Weldment	Single Vee Butt Weld
Welding Process	TIG/Manual Metal Arc
Dimension (mm)	12 × 300 × 300

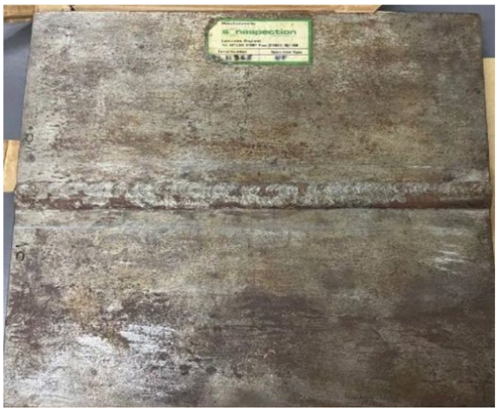


Fig. 2 *Single Vee Butt Welded test specimen*

2.1 Preparation Process

Preparation process is the process of preparing the sample, the transducer (probe), the choice of suitable and efficient couplant and UT's machine setup. For sample preparation includes these surfaces of the sample that is free from any foreign material or object at the testing area. It involves the area around the weldment and HAZ area. The illustration depicting the parent body is shown in Fig. 3.

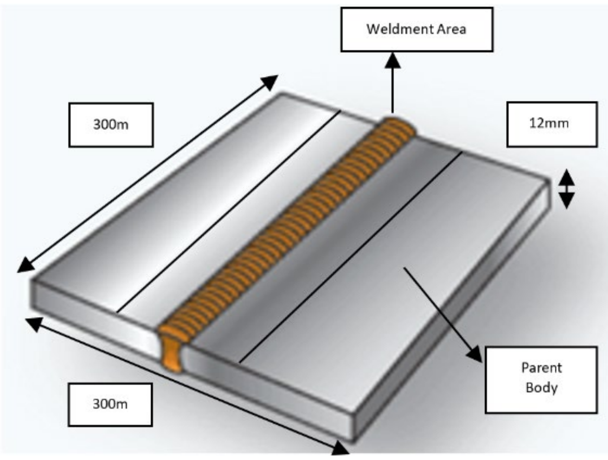
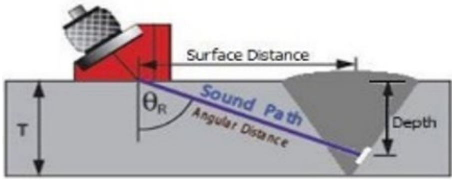
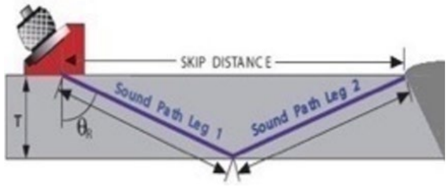


Fig. 3 *Illustration picture depicted the parent body, HAZ area and weldment area*

In a manufacturing process, finishing is used to give the workpiece a desirable texture. Through several procedures that fall under its purview, it helps us to obtain the desired surface polish, geometric structure, and precision [15]. However, to get an efficient and accurate results the cleaning should remove any loose scale and weld spatter to make sure the surface is very flat and not grumbling. This is to avoid difficulty of the probe during movement on the sample when scanning the sample.

Next, the chosen of suitable probe or transducer. In normal practice, common frequency used for material involved in this research are 2MHz and 4MHz with selection of three angles which are 45°, 60° and 70°. The angles that are used for this research are 45° for scanning root defect whereas 60° and 70° are for scanning the body defect of the weldment. The position for the probe is based on the calculation from formula in Table 2. Table 2 is simplification of calculation for the position of the transducer during the root and body scanning.

Table 2 *Formula for half-skip distance and full skip distance*

Features	Formula	Figure
Half-skip distance	$SD = \frac{1}{2} \times 2T \times \tan\theta_R$ $BP = \frac{T}{\cos\theta}$	
Full-skip distance	$SD = 2T \times \tan\theta_R$ $BP = \frac{2T}{\cos\theta}$	

*SD=Skip distance, BP=beam path length, HSD=Half-skip distance, FSD=Full-skip distance

Couplant used in this research is a water-based couplant consisting of wallpaper paste which is commonly used for industry. The setting for the machine included the adjustment of the value of material's velocity, sensitivity for different materials, determination of DAC curve and others. For the calibration, probe index calibration also known as beam path calibration it by using International Institute of Welding (IIW) or Institute of Welding (IOW) block. The reference block used for UTFD required two type of blocks which are V1 or V2 block used for probe index calibration and 18mm ASME block used for distance amplitude correction (DAC). Table 3 shows the detail of V1 Block and a block for Distance Amplitude Correction (DAC) curve.

Table 3 *Reference blocks with V1 block (upper) and DAC curve (below)*

Features	Purpose of Block	Calibration Block
V1 block	To calibrate the probe index of the transducer	
18mm ASME block	To perform a DAC curve on equipment	

Then, the selection of transducer consists of 2MHz and 4MHz with 45°, 60° and 70°. This is to differentiate the result between two frequencies with different angles of probe involved in this study to compare and determine which parameter has better efficiency and accuracy in terms of reading the sizing and characterization of the flaw. Next, the setup of the UT's machine must be accurate to get an efficient result by adjusting the value of material velocity, thickness of the materials, and other parameters on the UT's machine according to the detail of the test specimen. In this study ultrasonic testing provide the result on sizing and characterization of defect. Fig. 4 shows the general component used for UT testing.

(a) **(b)** **(c)**

Fig. 4 *(a) Rigor RFD 60 was the equipment used for UTFD in this study; (b) Probe 2MHz with 60°; (c) Probe 4MHz with 45°*

2.2 Calibration Process

This process must be done thoroughly due to its effectiveness in fabricating an efficient result for the data which consists of probe index calibration, p-delay adjustment, and construction of DAC curve. Probe index calibration also known as beam path calibration require the IIW V1 block or IIW V2 block as referred to ASME, Section V, Article 5 [15].

2.3 Probe Index Calibration

For probe index calibration there will be an indication to determine the distance from the index line to the edges of the block which the total length is 100mm for IIW V1 block and 12mm IIW V2 block as referred to the ASME Section V, Article 5 [16].

Firstly, Set the zero offset to zero and set velocity to the approximate shear wave velocity of the test material. Couple the transducer to the calibration block and observe the echoes from the reference reflectors. Adjust the instrument's pulser and receiver settings as required to obtain clean echoes. Settings typically include pulse frequency, energy, damping, receiver filtering, and gain.

Look at the echo from the 100 mm or 4-inch radius of the block. As shown in Fig. 5, to locate the point at which the echo peaks, move the wedge forward and backward. Most instruments have a peak memory function that can be used to create an echo envelope for confirmation. Note that if the velocity and zero calibration have not yet been performed, this peak will not appear exactly at the 100 mm/4-inch point on the monitor scale. After performing the probe index calibration, mark a line on the transducer where the angle beam calibrated clear as mentioned.

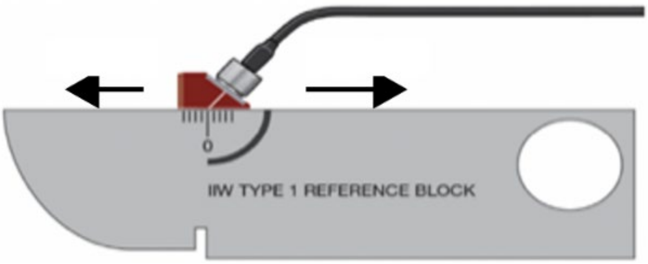


Fig. 5 *The process of probe index calibration*

2.4 Scanning Process

After the calibration process, scanning process is the main part of this study that needed to investigate carefully to determine the defect in the weldment area. A defect is normally characterized by observing their echo dynamic pattern as the probe is scanned in two directions, along and across the defects [17]. Before the scanning process begins, the calculation of certain parameters needs to be done such as full skip distance (FSD) and half-skip distance (HSD) as shown in Table 2. Location (depth & distance) of all above indication shall be investigated and interpreted by estimation of maximum sound path of related indication. To determine the proper scanning area for both sides of the weld, the inspector must calculate the skip distance of the sound beam using the refracted angle and material thickness. Other important information is given by the variation of signal in signal amplitude with swiveling the probe and orbital scans, with the directions of incidence of the ultrasonic beam. Scanning patterns can be determined by manipulating the probe as the way it is moved. Fig. 6 illustrates the pattern movement of the probe during scanning the sample.

Generally, it sums up that UTFD's probe also known as a transducer consist with various frequency and angle. In this study two different frequency and three different angles for each frequency are used as a manipulated variable of this study. It consists of 2 MHz with angle of 45°, 60° and 70° and 4 MHz with angle of 45°, 60° and 70°. After done with the scanning process, the data was validated by comparing the data collected through this study and the answer scheme of the test specimen that was checked by Sonaspection which also has a Certificate of Conformance as shown in Figure 7. The accuracy of the experiment data will be calculated as per Equation 1 below:

$$Percentage\ difference = \frac{Experimental - Actual}{Actual} \times 100\% \qquad (1)$$

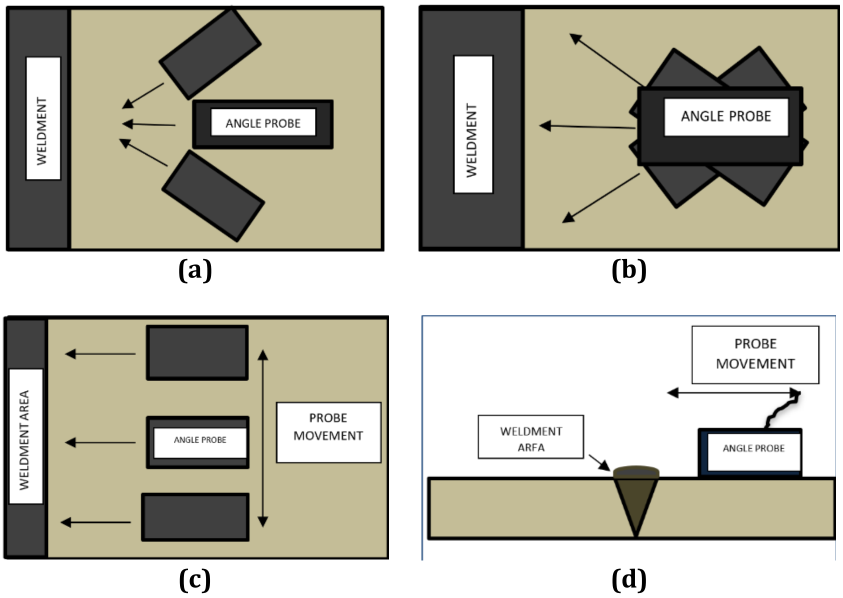
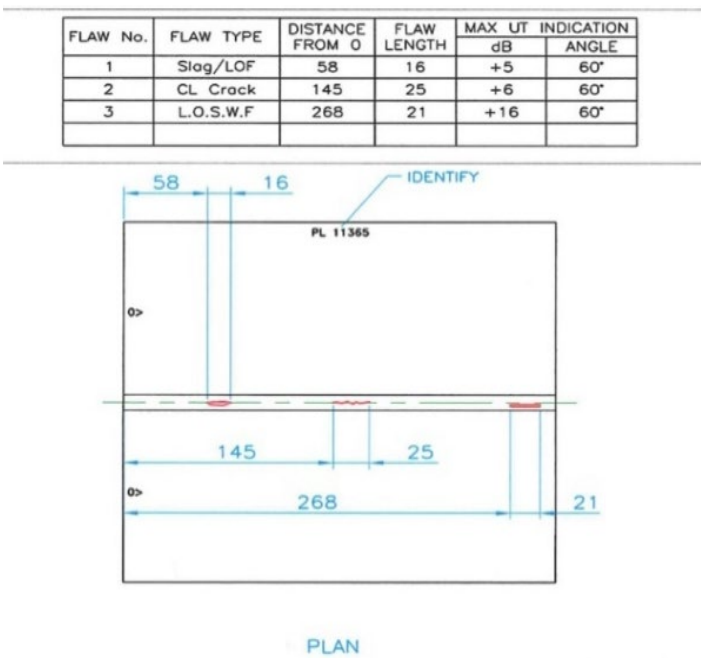


Fig. 6 *Movement of probe when scanning which are (a) Depth scan movement; (b) Swivel scanning; (c) Orbital scanning; (d) Lateral scanning*



FLAW No.	FLAW TYPE	DISTANCE FROM 0	FLAW LENGTH	MAX UT INDICATION dB	ANGLE
1	Slag/LOF	58	16	+5	60°
2	CL Crack	145	25	+6	60°
3	L.O.S.W.F	268	21	+16	60°

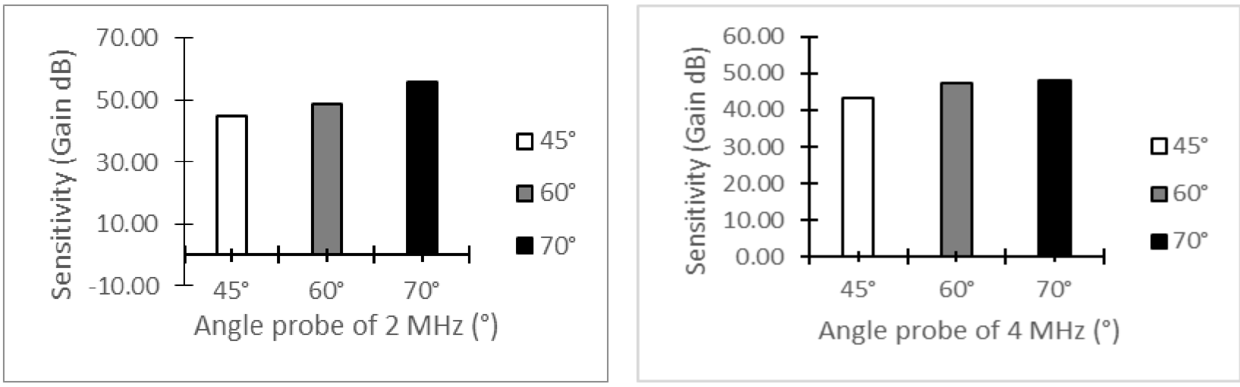
Fig. 7 *Answer scheme as inspected by Sonaspection*

3. Results and Discussion

This chapter produces the data comparison between two frequencies of transducer, 2 MHz and 4 MHz consist of 40°, 60° and 70° of angle probe each. From all the parameters involved in defect characterization process, it will come up with probe-delay (μs) and sensitivity (gain decibel, dB) produced by doing the probe index as shown in Figure 7. Other than that, distance of defect from datum of specimen, length of defect, height of defect, depth of defect and reference decibel of sensitivity will be examined from various type of method such as 6 dB drop, and 20 dB drop. After all data was obtained, it can be concluded which sensitivity and frequency of transducer that produce the most accurate defect characterization based on the acceptance criteria for ultrasonic testing on ASME, Section VIII, Division 1 [18].

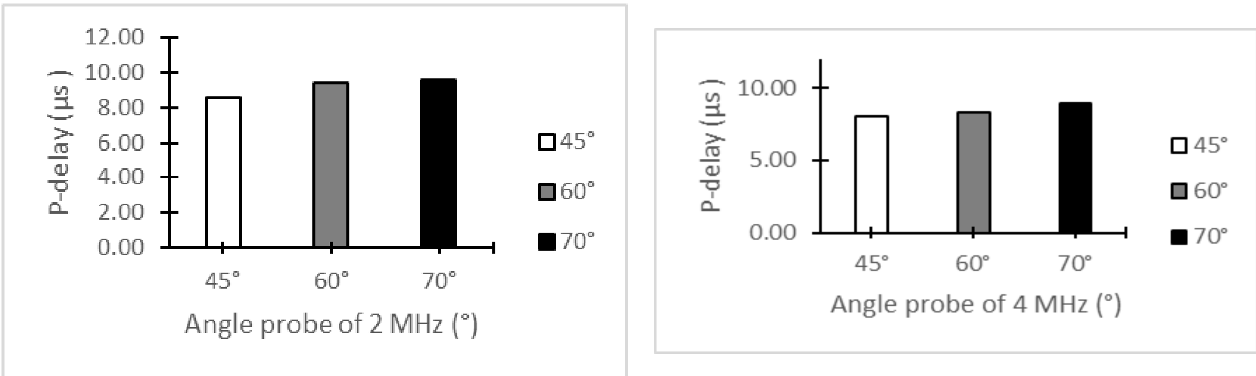
3.1 Sensitivity Versus Angle Probe

As per this experiment, ASME is used as the standard for calibration of UT inspection. On top of that, probe index needs to be done to execute the inspection and from this part of process the sensitivity of the UT's machine is important to get the better provision of the defect and the data of defect will exactly as per condition on which to base their flaw acceptance via proper standard, ASME [6].



(a) (b)

Fig. 8 *Comparison of sensitivity (dB) between different angle probes at (a) Frequency 2MHz; (b) Frequency 4MHz; both for carbon steel's specimen*



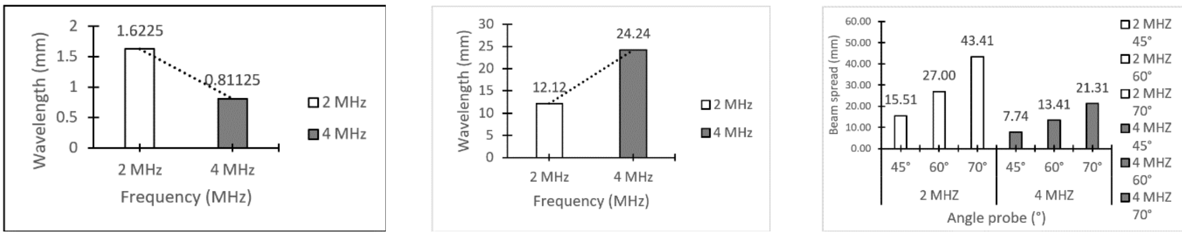
(a) (b)

Fig. 9 *Comparison of probe delay (μs) between different angle probes at (a) Frequency 2MHz; (b) Frequency 4MHz; both for carbon steel's specimen*

In Fig. 8(a), shows the sensitivity obtained from 2 MHz at 45°, 60° and 70° the higher the angle of the transducer, the higher the sensitivity (dB) or gain of UT machine which is 45.00 dB, 48.90 dB and 56.20 dB respectively which also shown in previous study of Ahmad A. et al (2018) [19]. While Figure 8(b), shows the transducer at 4 MHz at 45°, 60° and 70° showed that the higher the angle of the transducer also produce the higher sensitivity (dB) and resolution or gain of the machine which is 43.30 dB, 47.50 dB and 48.30 dB, respectively. In Fig. 9(a) the transducer shows that the higher the angle of the transducer, the probe delay (μs) was also increased. The probe delay of the 45°, 60° and 70° angle probe is 8.60 μs, 9.40 μs and 9.60 μs, respectively. While in Fig. 9(b), the probe delay (μs) gave the same trending as per 2 MHz pattern which is when the angle of the transducer increasing, the value of probe delay (μs) also increases, which is for angle probe of 45°, 60° and 70° the probe delay will be 8.06 μs, 8.28 μs and 8.97 μs. The statement is also supported by previous study done by Ahmad A. et al (2018) [19].

3.1 Frequency of Probe

Fig. 8 and Fig. 9 show the same trend which concluded that the higher the angle of transducer will produce the higher value for both probe delay (µs) and sensitivity (dB gain). The data obtained shows that the wavelength is related to the angle of beam spread as shown in Figure 11.



(a) **(b)** **(c)**

Fig. 10 *Relation between frequency and other parameter involved in calibration of angle probe (a) Frequency against Wavelength; (b) Frequency against Near Zone; (c) Frequency against Beam spread*

Fig. 10 present the frequency related to wavelength, angle prob, beam spread and near zone. In Figure 10 (a) and (b) prove that the wavelength produced by the lower frequency of transducer at 1.6225 mm has a longer wavelength than the higher frequency transducer at 0.81125 mm. Proven from the result also that the higher near zone required a higher frequency of transducer where at 2 MHz produce 12.12 mm near zone while 4 MHz produce 24.24 mm near zone. The wavelength affected the sensitivity at both frequencies 2 MHz and 4 MHz. Hence, it can be concluded that the longer of the wavelength, the higher sensitivity of UT machine and probe delay of the transducer [20]. This explains that the sensitivity of the machine by using higher frequency of transducer can give the optimum result of defect characterization where the less the sensitivity of the transducer can give an accurate measurement when doing the inspection. This statement is supported from the previous study which stated by Carovac A. et al (2011) [21].

In Fig. 10 (c) present the wavelength against beam spread where the beam spread of each transducer of 45°, 60° and 70° angle probe at 2 MHz and 4 MHz is calculated via the formula of beam spread [22] and has the manipulated variable on wavelength and the k as the constant variable for each different angle of transducer. For 2 MHz frequency at 45°, 60° and 70° angle probe the beam spread is 15.51 mm, 27.00 mm and 43.41 mm respectively while on the 4MHz transducer at 45°, 60° and 70° angle probe are 7.74 mm, 19.41 mm and 21.31 mm.

From this point of view shown that the higher the frequency the shorter the beam spread which also affected by the wavelength of the sound wave [21]. Basically, the beam spread affected by the angle of transducer, velocity of the material inspected, and frequency of the transducer as stated by previous study from Sanehiro Wada et al, (2013) [23]. Margaret M. Vernon et al, (2012) [24] state that the relationship between the wavelength, beam spread is that the transducer scanning range dependable on the material velocity, transducer frequency and the angle of transducer. Ng, A. et al, (2011) [25,26], stated that the higher the frequency of transducer will produce the shorter wavelength and better resolution with shorter beam spread compared to low frequency of transducer.

3.2 Defect Measurement on Carbon Steel

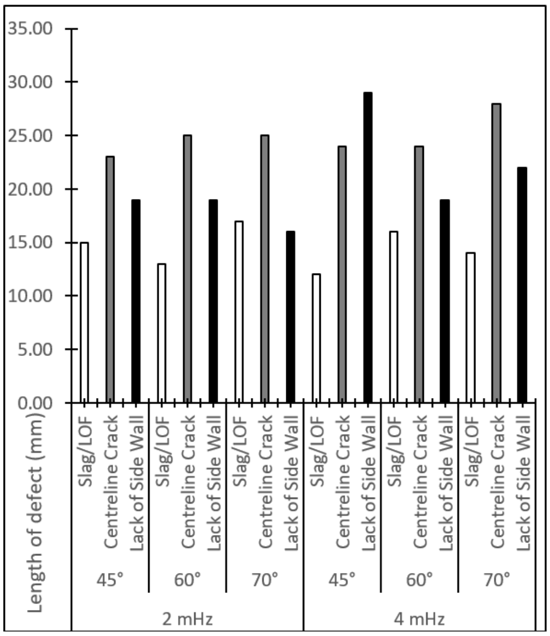


Fig. 11 *Graph depicted the defect measurement of the length of defect*

This research presents the length defect measurement on two different frequencies of 2 MHz and 4 MHz at 45°, 60° and 70° angle probes as shown in Fig. 12. Fig. 11 shows the tolerance of transducer with 4 MHz at 60° had the best tolerance value among other angle probes that been through the UT inspection. The tolerance value on defect of lack of side wall is -2 with percentage difference of 9.5%, centerline crack recorded at -1 with 4% percentage difference and slag or lack of fusion has no percentage difference towards the actual data and provided result same value of the answer scheme.

4. Conclusion

To sum up all the data stated above, this study has developed a range of ideal transducers to inspect a carbon steel plate with 12mm thickness to achieve a stable reading of UT data. It can be deduced that 4 MHz at 60° angle probe provide this research with the most accurate measurement compared to all the angle probe that being tested with the same parameter of material and sensitivity setting. This outcome stated that the relationship between the wavelength and beam spread is that the transducer scanning range is dependable on the material velocity, transducer frequency and the angle of transducer [27]. The higher the frequency of transducer will produce the shorter wavelength and better resolution with shorter beam spread compared to low frequency transducer.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

*The authors confirm contributions to the paper as follows: **study conception and design**: Muhammad Adam Baduhalin, Eliza M. Yusup; **data collection**: Muhammad Adam Baduhalin, Abdul Syahmie Azri Abdul Rani; **analysis and interpretation of results**: Muhammad Adam Baduhalin, Abdul Syahmie Azri Abdul Rani, Eliza M.Yusup; **draft manuscript preparation**: Muhammad Adam Baduhalin, Muhammad Nur Farhan Saniman, Eliza M. Yusup. All authors reviewed the results and approved the final version of the manuscript.*

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