EFFECT OF DEFECT ORIENTATION IN PIPE ON ACOUSTIC WAVE PROPAGATION

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Report

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Universiti Teknikal Malaysia Melaka

2017

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A report submitted
in fulfilment of the requirements for the degree of
Bachelor of Mechanical Engineering (Plant & Maintenance)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2017

DECLARATION

I declare that this project report entitled "Effect of Defect Orientation in Pipe on Acoustic Wave Propagation" is the result of my own work except as cited in the references.

Signature : ....

Name : Saddam Hamood Ali Mohammed Abbas

Date : 17 June 2017

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Plant and Maintenance)

Signature : ....

Name of Supervisor :Dr. Nor Salim Bin Muhammad

Date : 17 June 2017

DEDICATION

I would like to dedicate this humble effort to

Those who care about me when I need support and motivation

My father

HAMOOD ALI MOHAMMED ABBAS

To whom I miss, my late mother

MALEKAH AL-SHERHARI

To my supporting

Family

To whom give me much of his time and knowledge

My supervisor,

DR. NOR SALIM BIN MUHAMMAD

To my lovely country

YEMEN

To my second home

MALAYSIA

and

To all my friend,

for their assistances & supportive efforts.

ABSTRACT

Guided wave in non-destructive testing (NDT) and structural health monitoring (SHM) is a technique to perform an inspection in large or long structures such as in pipes from single position of transducer. There are three types of guided wave modes in axial direction of the pipe, which are torsional *T* (0, *n*), Longitudinal *L* (0, *n*) modes, and flexural *F* (*M*, *n*) modes. In low frequency range, the guided wave can only propagate in modes of *L* (0, 1), *L* (0, 2) or *T* (0, 1) in pipe structures. *L* (0, 2) mode is a typical mode that use in inspection technique due to its fastest wave speed and small dispersion in low frequency range. Therefore, we decided to investigate its behavior on the orientations of defects, which placed at the similar location in two aluminum pipes. The study used two-angle beam transducers consist of piezoelectric of transducers and acrylic shoes to find the artificial defects with placed in perpendicular and oblique orientations, respectively. The two angle beam transducers is used on the top and bottom of pipe and measured at five different locations with distance of 14 mm between each location. The five signals are then used to enhance the defect echo, which obtained from the excitation of five cycles of tone burst signal generated at central frequencies of 80 kHz to 150 kHz. The location of perpendicular defect is successfully located approximately at the exact location of the defect while the location of oblique defect is not unsuccessfully identified by using the two-angle beam transducer. This indicated that the reflected wave from defect is affected by the orientations of defects in pipes.

ACKNOWLEDGEMENT

In the beginning, I would like to express my full gratitude to Allah for granting me the best condition of health and strength in completing my final year project. My deepest thanks to **Dr. NOR SALIM BIN MUHAMMAD** for his time, guidance and support, and for his unfaltering professionalism and devotion in his activities both as an academic and as a supervisor in these two semesters. Respectfully, very special appreciation to all technicians in FSAB, **Eng. AZHAR** and all the staff in charge in UTeM facilities for giving me full assistance and additional knowledge in helping me to complete my research. Besides, I offer all thanks and appreciation to all my friends for their support. Last but not least I can only express my gratitude and thanks to my lovely family father, brothers, sisters, cousins for their help, support, motivation to achieve my goal. Finally, appreciation to Universiti Teknikal Malaysia Melaka for giving me the chance to complete my undergraduate program and gaining a lot of priceless knowledge for my future career.

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NDT	Non-Destructive Testing
SHM	Structure Health Monitoring
UT	Ultrasonic Testing
GW	Guided Wave
PZT	Piezoelectric Transducer

LIST OF SYMBOL

A0	=	Antisymmetric mode 0
A1	=	Antisymmetric mode 1
L (0, 1)	=	Longitudinal mode 0, 1
L (0, 2)	=	Longitudinal mode 0, 2
S0	=	Symmetric mode 0
S1	=	Symmetric mode 1
T (0, 1)	=	Torsional mode 0, 1
T (0, 2)	=	Torsional mode 0, 2

CHAPTER 1

INTRODUCTION

1.1 Background

In line to the high demand in manufacturing and services there are many companies involved in business of power plant and petrochemical industries which use storage tanks, pressure vessel, and pipes in their facilities for storage, transfer and distribution. There are different ways for the installation of pipes on ground installations or underground installations. In addition, some of the installations have external coating of bitumen, polyethylene, polypropylene or asphalt. The flow of fluids and foreign materials in fluid transfer and distribution cause internal corrosion in the pipe networks. The cyclic loading on the pipe network also contribute into pitting in the pipeline while the effect of the environment also possible to cause external corrosion on the pipes. Therefor a predictive maintenance needed to ensure the quality of the pipe works, as well as to ensure non-stop operational capability of the factory and to prevent leakage in the pipes that carry the fluid materials or the gases as these fluids or gases might be harmful to human or caused the pollution into the environment. Moreover, in order to detect or screen the structure even for external failures using traditional ultrasonic technique will be very expensive due to the excavation, removal of the pipe insulation, and reinstallation of the pipe structures.

Therefore, the scientists have worked out on the development of a fast and reliable method for the detection of corrosion under insulation and underground pipelines. Ultrasonic guided wave in Non-destructive testing (NDT) structural health monitoring (SHM) contributed to solve these industries failure (Saeed Izadpanah, Gholam Reza Rashed, Sina Sodagar, 2008).

By using the guided wave technique, the maintenance activity can be carry out with the sufficient knowledge and skills to perform the inspection for the pipes above ground and underground. The guided wave can be utilized to locate defect externally or internally to ensure the quality of the pipe works, as well as to ensure non-stop operational capability of the factory and to prevent the pollution in the environment (Alobaidi et al., 2015).

Ultrasonic guided wave in solid media have become a critically important subject in NDT and SHM. New faster, more sensitive and more economical ways of looking at materials and structures have become possible when compared to the previously used normal beam ultrasonic or other inspection techniques. (Joseph L. Rose, 2014).

There are many advantages of using guided wave summarized as follows:

i. Perform an inspection for long distance as in the pipe from only single position of transducer, that's means no need to scan entire structure under consideration, data can be obtained from a single probe position.
ii. Provide greater sensitivity even in lower frequencies can produce a better picture of the health of the material than the obtained data in normal beam ultrasonic inspection or the other NDT techniques.
iii. The ultrasonic guided wave analysis techniques can perform inspection even for the hidden structure, coated structure as in Figure 1.2 below.
iv. The inspection and guided wave propagation are cost effective because it is simple and rapid.

Guided wave inspection named" long range inspection" as technical name, the volumetric inspection is also known by a guided wave inspection used mainly to locate the pipe integrity as a fast screening tool for corrosion. Guided Waves are ultrasonic waves that guided by the object geometry in which they propagate. (Saeed Izadpanah, Gholam Reza Rashed, Sina Sodagar, 2008).

The guided wave inspection on pipe will conducted in this research experiment using an angle beam transducer, which consists of a transducer and a shoe. However, multiple of transducers might be required for a specific application when the inspected pipe defect in different orientations. Thus, a technique on transducer and equipment development must realize to suit the requirement on inspection to perform the inspection for pipes to detect the location of defects in different orientations to reduce the cost and provide competitive services.

1.2 Problem Statement

Applications of guided wave technique in pipe inspection become more dominance for inspection of underground pipelines. However, corrosion defects in pipes occurs in verity of depths, sizes, geometries, and orientations. In some cases, the guided wave screen in pipes might fail to locate severity defects due to low sensitivity of the transducer against the defect geometries or orientations.

This study aimed to investigate the effect of defect orientations on the guided wave inspections by using a perpendicular and an incline defects in pipes. The results then will extended for signal enhancement to improve the sensitivity of defect screening in pipe structures.

1.3 Objective

The objective of the research to achieve following:

- Observe the effect of defect orientation on the sensitivity of a guided wave pipe inspection.

1.4 SCOPE OF STUDY

The scope of this research consists the experimental works to cover the following:

1. Design and fabricate the matching layers, backing layers, and casings for the PZT transducer and its shoes.
2. Create an oblique defects in the aluminum pipes to detect this effect with 45 degree.
3. Development of guided wave measurement system.
4. Analysis of defect locations in pipe using the measured signal from angle beam transducer.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter covers the literature review about guided waves inspections in two common structures use in industry, which are pipes and plates. It discusses dispersion curves and the transducers used in the guided wave inspection.

2.2 Ultrasonic bulk wave and guided wave propagation.

Ultrasonic bulk wave that propagate in the media with no boundaries, such as the waves traveling in infinite media. Nevertheless, guided wave characterized by it is required boundaries in order the propagation like in rods, pipes, plates. Guided waves naturally can propagate for the long distance provide tremendous potential for time in order to cost savings during the inspection for deferent structures. As shown in the Figure 2.1 below the guided waves able to achieve much ranges of inspection than conventional “bulk” ultrasonic testing methods, because the guided wave use the structure as a waveguide by using resonances between the boundaries of the structure itself, such as the plate surface or the outer diameter and inner diameter of a pipe. Conventional “bulk” wave UT systems able only to inspect an area that is very close to or directly under the transducer. In the bulk wave inspection, the transducer also must scanned along the surface of the structure in order to access to information in axial direction. On the other hand, guided wave systems can detect flaws for long distance from single probe transducer. It also able to locate defects at very low frequencies compared to conventional “bulk” wave UT, which reduce attenuation of the wave modes (Joseph L. Rose, 2014).

Traditional ultrasonic and guided wave techniques as shown in Figure 2.1, to cover inspection on a large area of the structure. The ultrasonic technique introduces wave in thickness direction at higher frequency range (1 MHz - 15 MHz) while the guided wave generates acoustic wave in longitudinal direction either from an angle beam transducer or an array of transducers at lower frequency (50 kHz - 15 kHz). (Joseph L. Rose, 2014).

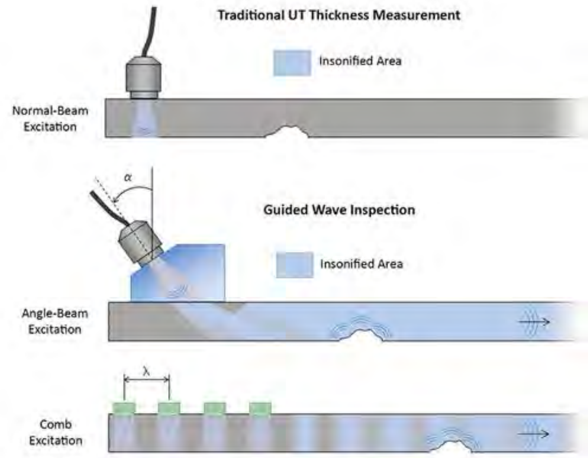


Figure 2.1: Comparison between bulk wave and to guided wave method (Joseph L. Rose, 2014).

2.3 Guided Waves

Guided waves started in industries in early 1990s for cost reduction on screening large structures. It is one of non-destructive testing (NDT) in structure health monitoring (SHM). The guided wave (GW) well known by its ability to perform inspection over long distance of pipelines or large structures. The Guided Wave (GW) typically used on inspection of whole structures from single probe location. The technique than can be used for service inspection in many different structures such as rods, pipes, thin plates, and multilayer structures. Its ability to perform rapid screening in long or large structures significantly reduce the operation costs during the inspections.

Furthermore, guided waves have the ability in inspection of hidden structures such as under water or ground structures, insulated pipes and concrete structures as shown in Figure 2.2, it is due to the behavior of the excited guided wave modes which can propagate through fluids or along the solid medias from a fixed probe(Rose, 2007).

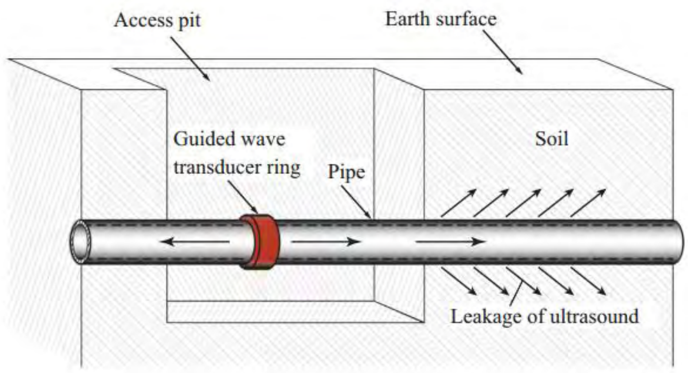


Figure2.2: Performing inspection for hidden pipe with by guided waves

2.3.1 Lamb wave propagation in plate

Horace Lamb studied the wave propagation at an isotropic solid plate with free surface (Lamb, 1917), Lamb waves a common waves used in plate detection of NDT. Lamb waves propagation are parallel to the surface plate during the thickness of the pate materiel. Properties of the plate, that effect the propagation of Lamb waves such as density and the elastic. In addition, they can effect a great deal by test frequency and material thickness. Lamb waves propagate at incident angle at which the wave velocity in the source is similar to the wave velocity in the plate material. Lamb waves is capable to travel long distance of the plate. A several modes of particle vibration are possible, and the most common are fundamental symmetrical and non-symmetrical modes as illustrate in Figure 2.3. Symmetrical modes (S-mode) has motion in a symmetrical pattern around the medium of plate surface. It is known as the extensional mode because of the wave is "stretching and compressing" the plate in motion direction of the wave. Symmetrical mode of wave motion is most efficiently propagated when excitation force parallel to the plate surface (Auld, 1990; Rose J. L., 1999).

Asymmetrical (A- mode) commonly denoted as flexural mode due to a large portion of motion moves at normal direction into the plate, also small portion of motion moves parallel direction in the plate.

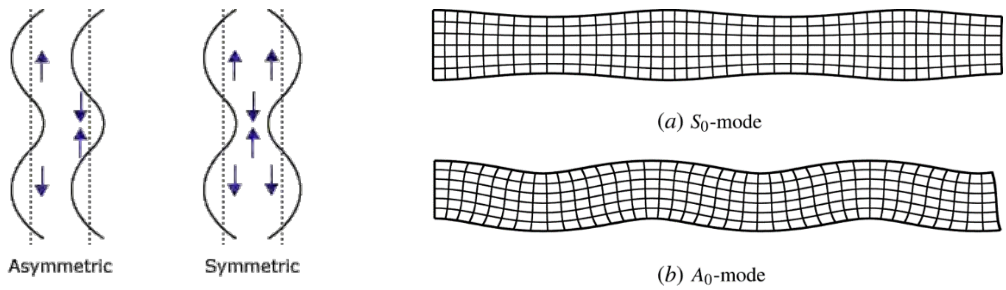


Figure2.3: Symmetric mode (s-mode) and asymmetric mode (A-mode) (https://www.nde-ed.org)

2.3.2 Guided wave propagation in pipe

Guided wave in pipes depend on the surface of outer and the inner diameters of the pipe in order to propagate in wall of the pipe in long axial distances; therefore the properties of the guided waves can be determined from the diameter (thickness) for the pipe and the material of the pipe . The characteristics of the guided waves for pipes influenced by the thickness of the pipe wall. Figure 2.4 shows Guided wave propagation in pipe (Rose, J. L., Cho, Y., & Avioli, M. J.,2009).

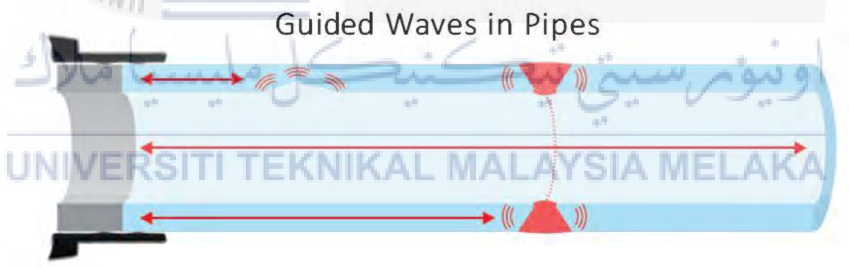


Figure2.4: Guided wave in pipe (http://www.gwultrasonics.com/knowledge/pipe/)

The propagation of guided waves for pipes can be circumferential and axial direction. By the precise pipe boundary conditions and solving the governing equations of wave, the wave's generated behavior can be explained. There are several numbers of modes for guided wave to the pipelines. The Selection of the better modes for an inspection pipe is a necessary in order to understanding the guided wave propagation of inspection sensitivity. The circumferential order M and mode number n typically used to denote the guided wave modes for pipe. There are three type of modes are possible as shown in the Figure 2.5 below torsional, longitudinal and flexural. These guided wave modes propagate in axial direction for the pipe. When M=0, this indicate that the acoustic fields of modes are axisymmetric along the pipe circumference, on other hand, non-axisymmetric. torsional T(0, n) also Longitudinal L(0,n) modes are axisymmetric, but the flexural modes F(M, n) are non-axisymmetric modes (Rose, 2014).

The axisymmetric longitudinal mode L or torsional mode T that has regular energy distribution in a circumference of pipe. The non-axisymmetric flexural modes, that are guided waves which spiral down of the pipe at some angle to the pipe's axis, which means that distributed of energy is not regularly distributed in the pipe circumference. Then the inspection of the pipe can be perform by using fundamental axisymmetric pipe modes (Takahiro Hayashi, Joseph L. Rose, January, 2003).

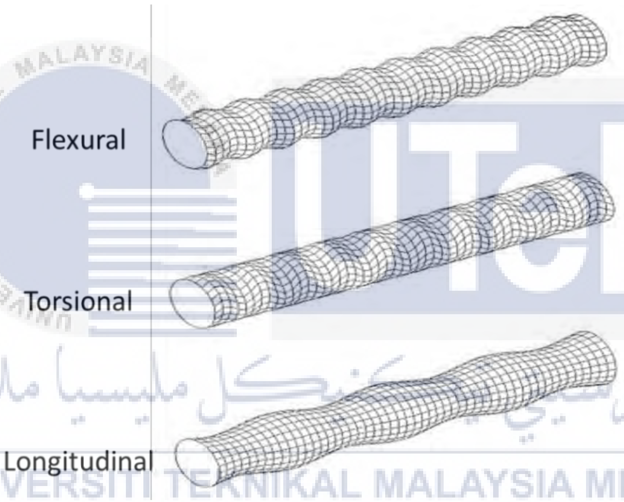


Figure2.5: The axisymmetric mode torsional and longitudinal in pipe, as well as non-axisymmetric mode flexural (http://www.gwultrasonics.com/knowledge/pipe/)

2.4 Dispersion Curves

Dispersion curves display a constructive interference region, which may happen as result of reflection of waves inside a structure, explaining the types of waves and modes that could propagate. We predominantly at once produce a several modes which called as the zone of excitation (Rose, 2002).

As the guided waves depend on the properties of the structure, its velocity is a function material thickness and frequency. Dispersion curves are represent the graphical of frequency and phase velocity, the group velocity of a particular material thickness. In order to draw the dispersion curves we must have solutions for phase velocity with frequency time's thickness. The solutions derived by solving governing equations of the wave propagation. The Raleigh-Lamb frequency relations recognized as the dispersion equations for the plate. The equations as below, by solving these equations, we will be able to plot the dispersion curves using the only the real solution. (S. Adalarasu, 2009)

Symmetric modes:

$$\tan(qh) / \tan(ph) = 3D - (4k^2 pq / (q^2 - k^2)^2 \qquad (2.1)$$

Anti- symmetric modes:

$$\tan(qh) / \tan(ph) = 3D - ((q^2 - k^2)^2 / 4k^2 pq) \qquad (2.2)$$

Where:

$$p^2 = 3D\ (\omega / (C_1^2 - k^2)) \qquad (2.3)$$

$$q^2 = 3D\ (\omega / (C_t^2 - k^2)) \qquad (2.4)$$

Wave number k obtained from

$$k = \left(\frac{\omega}{C_p}\right)$$

Where C_p is the phase velocity also known by V_{ph} for the Lamb-Wave modes, and omega is circular frequency and D is the thickness of the medium.

The relation that relates the Phase velocity to the wavelength is

$$V_{ph} = 3D\ (\omega / t_p)\ \lambda \qquad (2.5)$$

For the pipe, many software programs that developed in order to plot the dispersion curves by inputting specific parameters for the structure such as pipe or plate.

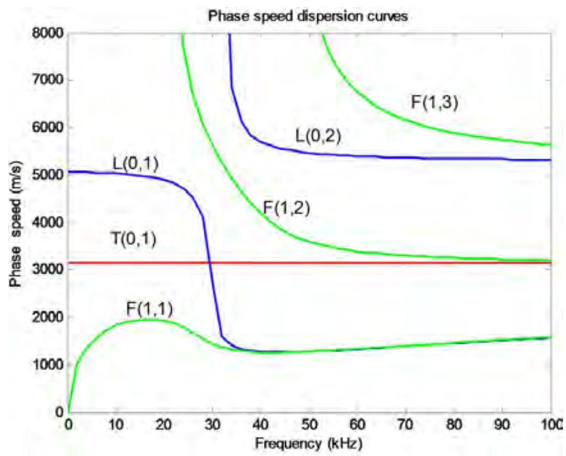


Figure 2.6: Example of dispersion curve for Phase velocity of stainless steel pipe that has outer diameter 56 mm (Y. M. Wang*, C. J. Shen, L. X. Zhu, F. R. Sun).

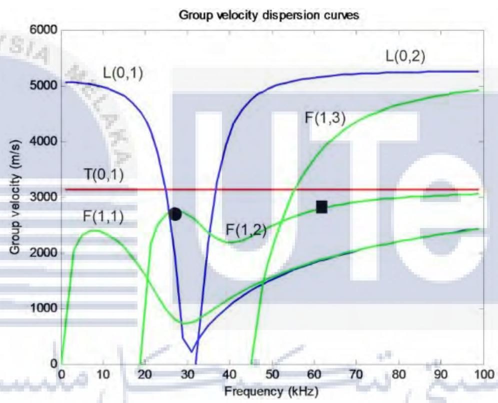


Figure 2.7: Example of dispersion curve for group velocity of stainless steel pipe that has outer diameter 56 mm. (Y. M. Wang*, C. J. Shen, L. X. Zhu, F. R. Sun)

The previous Figure 2.6 illustrate the dispersion curve of phase velocity which describes the speed of wave propagation at particular phase while the Figure 2.7 shows the group velocity that describes the speed of wave propagation at particular packet. The modes that used in the inspection in the most cases are torsional and longitudinal modes because the considered as axisymmetric modes. Flexural modes known as non-axisymmetric modes which usually propagate simultaneously with the longitudinal modes (Lee, Park, Jo, & Choi, 2006)

Typically for the material like Steel and aluminum, in the range of the low frequency from DC to 400 kHz, the existing modes L (0, 1), L (0, 2) and T (0, 1). The torsional mode (shear mode) will not be visible when the waves excited by normal direction of transducer on the pipe surface. L(0,2) mode used in inspection technique, this mode characterized by being fast and non-dispersive, has extremely simple deformation shape and has axial of membrane elongation of the wall of pipe, with axial symmetry(Alamos & Stupin, 1998).

2.5 Defects location (echo) in pipelines

The propagation of guided waves in pipes there are a lot of techniques, but the two of the most widespread shown in the Figure 2.8. The angle beam transducer used to generate the guided waves via pulsing a piezoelectric element on the shoe that placed on the surface of pipe. Torsional or longitudinal guided waves, which induced into pipe body and propagated along the pipe wall. Once these guided waves distinguish pipe feature as weld, pipe branch, corrosion and pipe bend they reflect back to the sensors at the single location of wave initiation. These signals captured and then analyzed. The time travel for each single calculated in order to identify the location of defect from the sensor. The amplitude of the defects to determine the importance of defect(Rose, 2002).

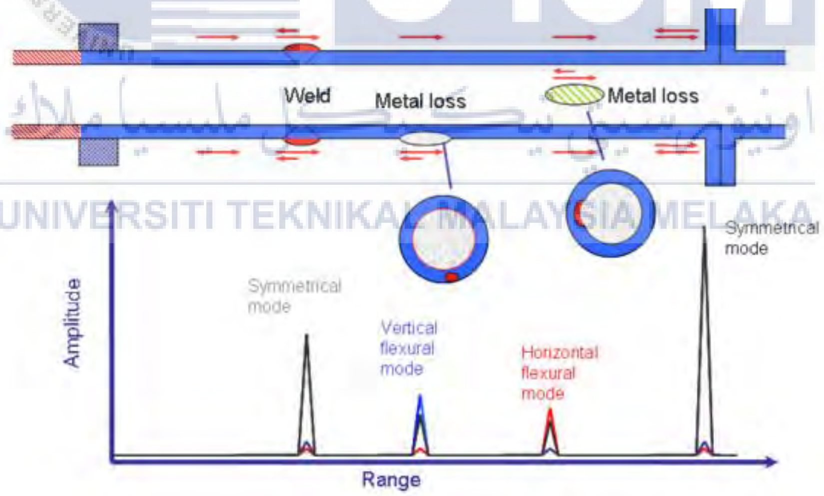


Figure 2.8: Defects location (echo) in pipe

2.6 Piezoelectric transducer (contact type)

The transducers are extremely important element of the ultrasonic apparatus system, transducer combine piezoelectric element that can converts electrical signals to mechanical vibrations as transmit mode, also convert mechanical vibrations to electrical signals as receive mode. There are factors, inclusive mechanical and electrical construction, materials, also the external mechanical and electrical load conditions, which effect the behavior of a transducer. For the mechanical construction, consist the radiation surface area, mechanical damping, housing, and type of connector also another variables for physical construction. Figure 2.9 shows example of piezoelectric transducer (Miodrag Prokic, 2004).

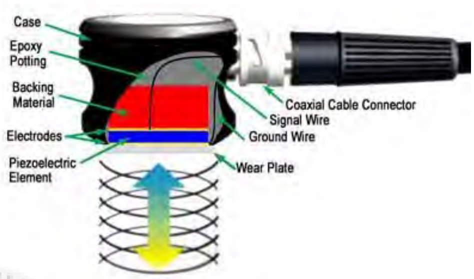


Figure 2.9 Example of piezoelectric transducer (https://www.nde-ed.org/EducationResources.htm)

The piezoelectric element cut into 1/2 the required wavelength. An impedance matching is located between the face of transducer and the active element in order to get as much as energy out of the transducer. For good impedance, matching can achieved by sizing the matching layer to be its thickness is 1/4 of the required wavelength. This will keep the waves reflected through the matching layer at the phase when the waves exit the layer as explained in the Figure 2.10 below. For the contact transducers, the matching layer made from a material that has an acoustical impedance between an active element and steel. (Ihara, 2008).

For the backing material to support the crystal which has a great effectiveness on the damping characteristics of the transducer. By using the backing material and an impedance similar to the active element will produce an effective damping. Furthermore, the transducer can have a wider bandwidth leading to higher sensitivity. In addition, the mismatch in an impedance between active element and backing material will increases, material penetration increases but transducer sensitivity is reduced.

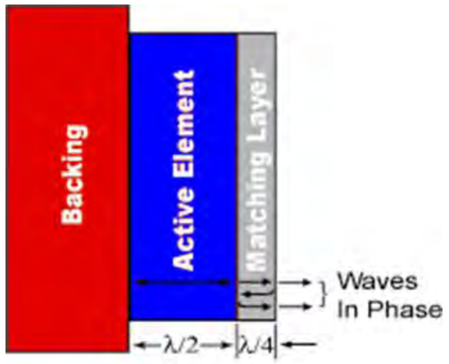


Figure2.10: The construction of the piezoelectric transducer (https://www.nde-ed.org/EducationResources/CommunityCollege/Ultrasonics/EquipmentTrans/characteristicspt.htm)

2.7 Angle beam transducer

There are many transducer to excite the guided wave and one of them is angle beam transducer this commercial transducer is the most common technique used in ultrasonic guided wave inspection (Joseph L. Rose. 2002).

The function of the transducer is to transmit a guided waves through the structure, and reflected echoes referring the existence of defects or other structural failures (Cawley & Lowe, 2003). Angle beam transducer that consist of a transducer casing and a shoe is very important for ultrasonic non-destructive testing. Usually used in a variety of inspection applications, as well as for detection of cracks that oriented perpendicular to the surface in different structure such as metal plates, billets, pipes, forgings, machined and structural components Figure 2.11 shows the angle beam transducer.

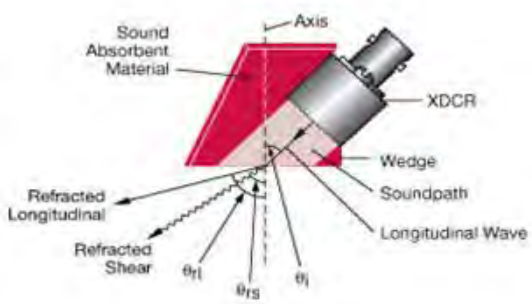


Figure 2.11: Angle beam transducer (http://www.olympus-ims.com/en/ndt-tutorials/flaw-detection/weld-inspection/).

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter explains the methodology of this project, which aimed to study the effect of defect orientation in pipe on acoustic wave propagation. The investigation performed on the aluminum pipes with defects in circumferential direction (called as perpendicular defect) and oblique defect at 45 degree to the axial direction.

Therefore, in order to carry out this research of experiment, the preparation works including the design of transducer casings and transducer shoes have conducted before the final fabrications. The evaluation of the transducer shoes validity of defect needed by comparing the signal obtained to the theoretical value. Then fabricate the defect on the pipe in perpendicular and oblique orientations before proceeding to the defect inspection.

The set up for the angle beam transducer in multiple transducers in circumferential direction is also proposed to reduce noise in signals and to cancel the unwanted flexural modes if exist.

Furthermore, the signal processing of the moving average considered in order to enhancement sensitivity of defect location in pipe with perpendicular and oblique defect. The final waveform will analyze in order to evaluate the sensitivity of mode L (0, 2) on detections of perpendicular and oblique defect in pipes.

3.2 Experimental Flow Chart

In the Figure 3.1 below the flow chart for this research of experiment that illustrate the steps to investigate the objective of this experiment in two semesters.

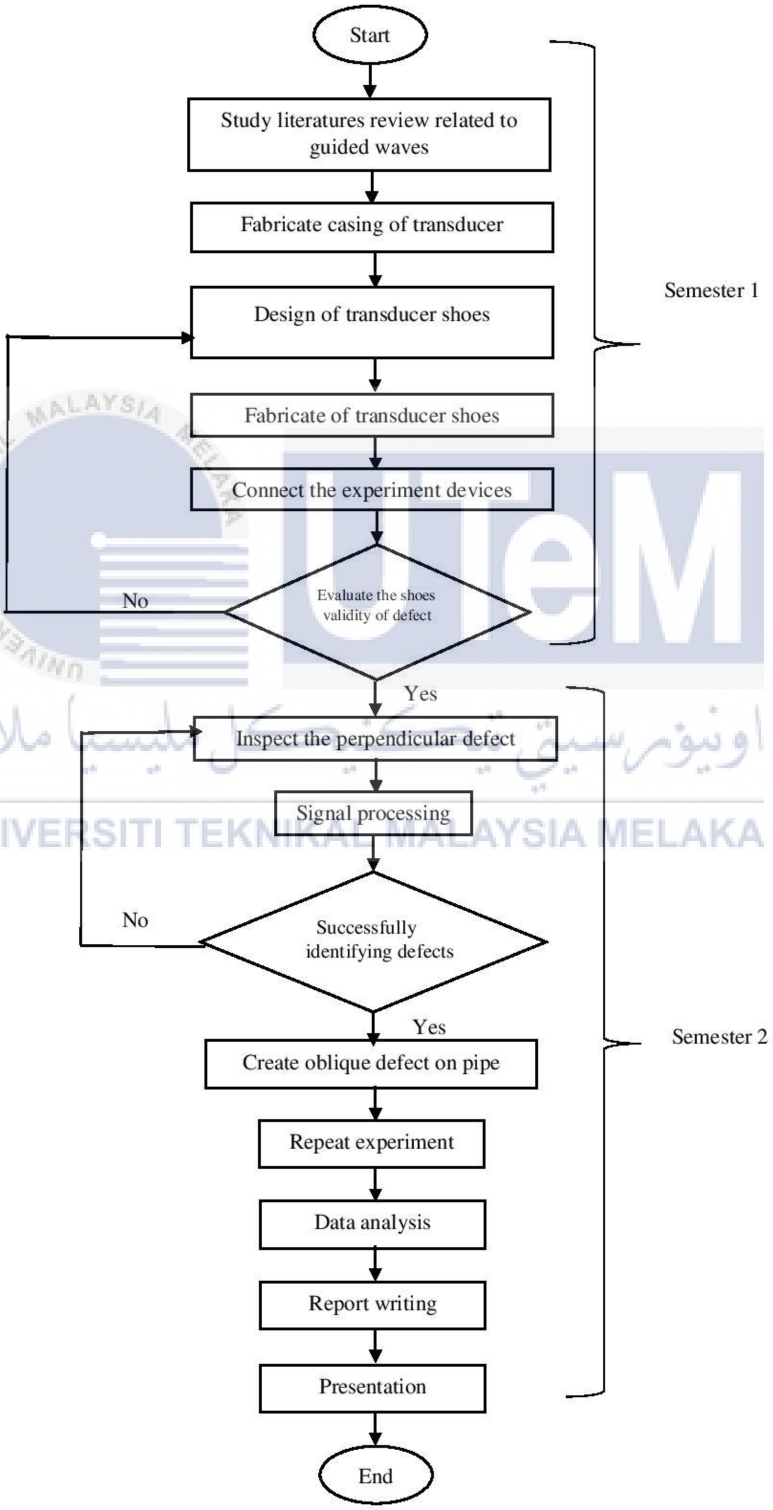
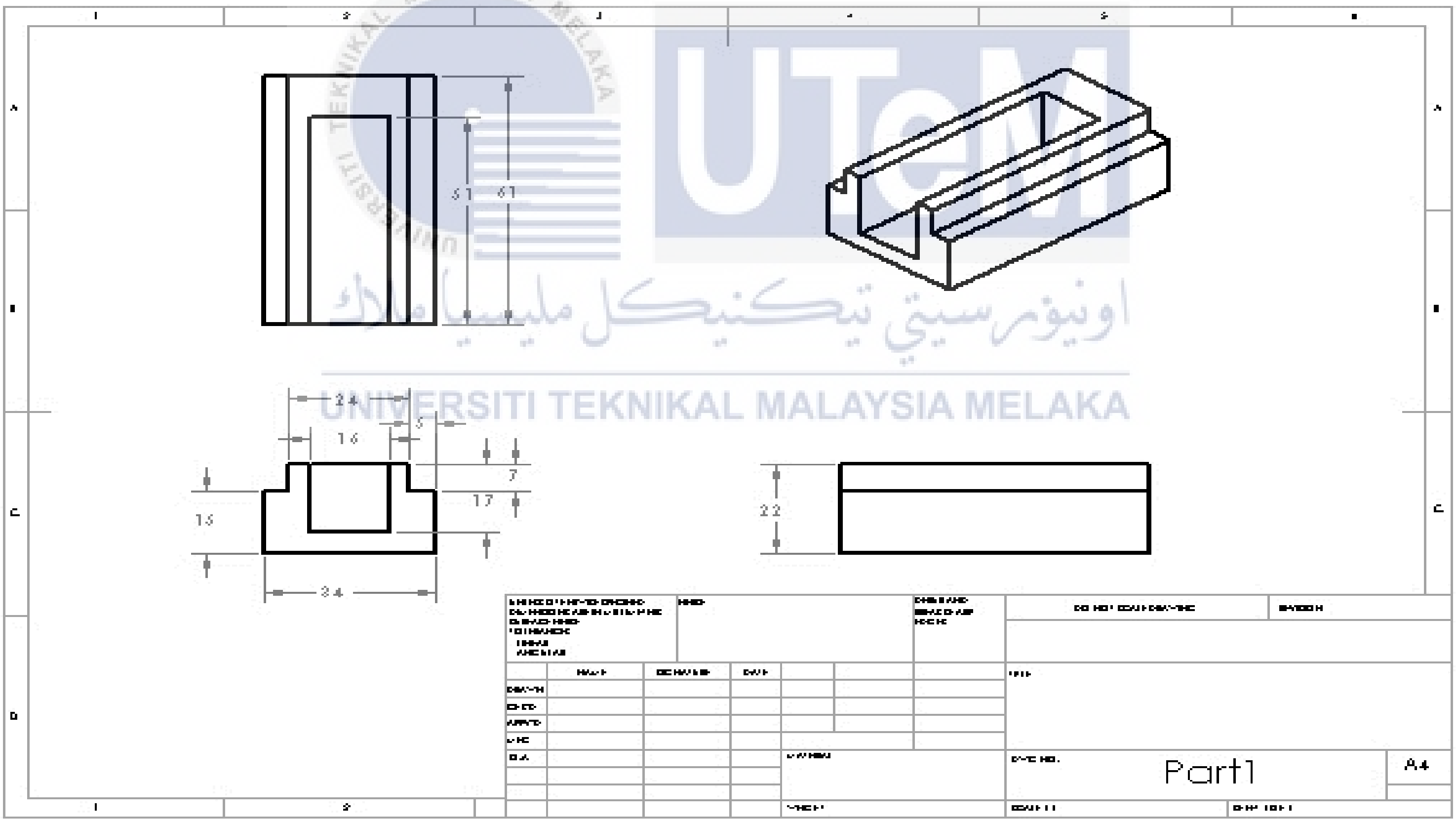


Figure 3.1: Evaluation of defect orientation in the guided waves pipe inspection

3.3 Transducer Casing Design and Fabrication

3.3.1 Transducer Casing Design

The transducer casing have been designed by using solid works software based on the dimensions for the old transducer casing in the maintenance laboratory, the target for the design is to improve the transducer performance and reduce the unwanted RF noise due to the bare wire connection. The new casing will connected by BNC connector to reduce electrical noise, which might cause by the bare wire connection. The following Figures 3.2 and 3.3 show the detail design for the transducer casing and the Figure3.4 is the type of BNC connector used for the transducers.



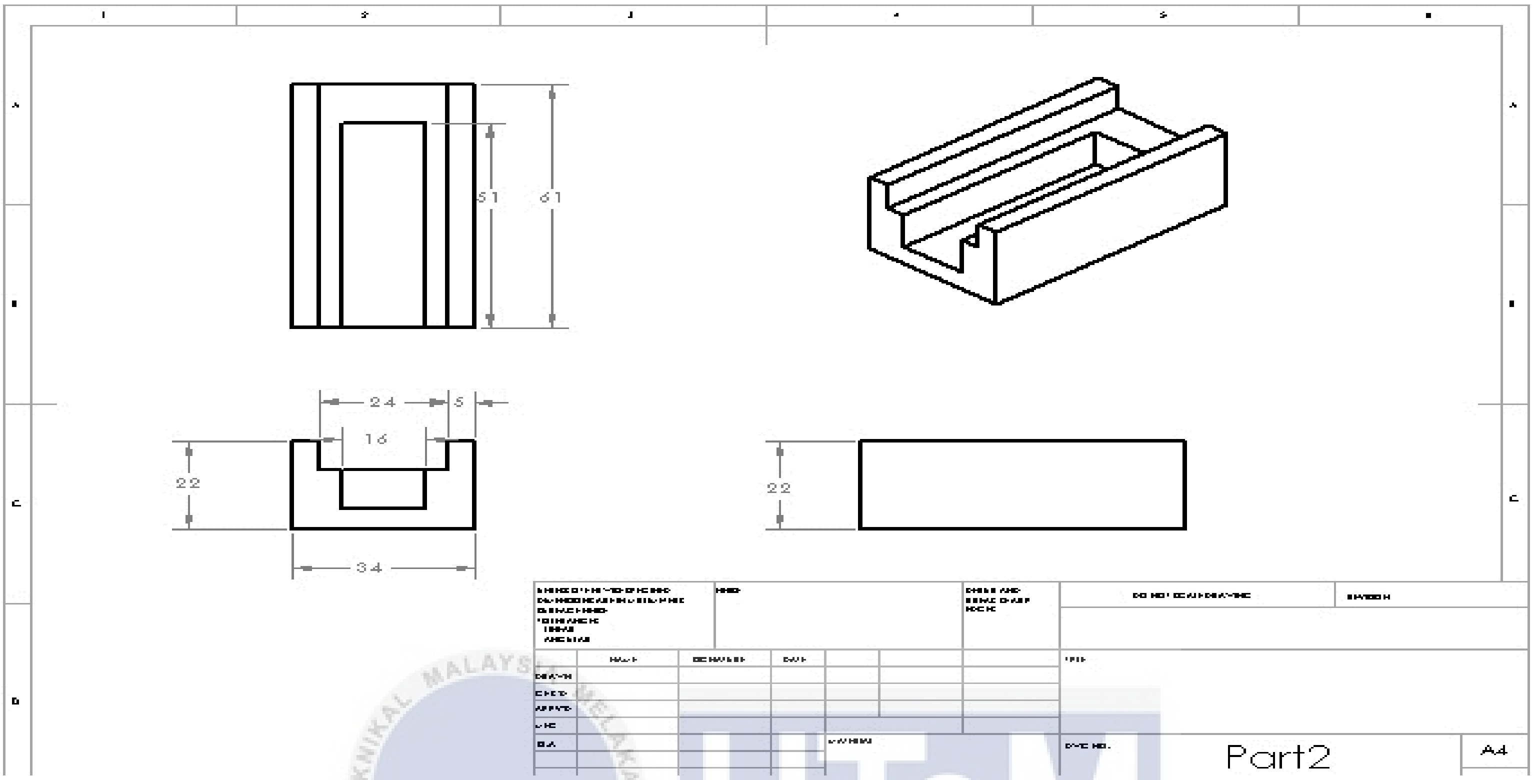


Figure 3.2: Detail design of transducer casing part1 and part2

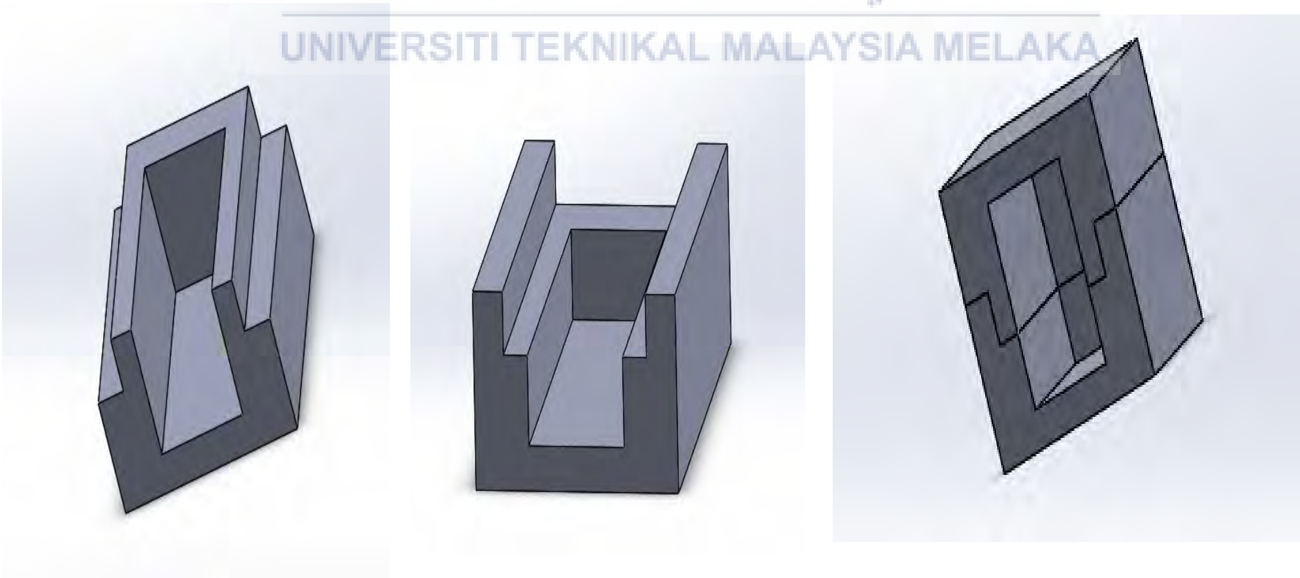


Figure 3.3: 3D design of transducer casing part1 and part2

3.3.2 Transducer Casing Fabrication

By using the vertical milling machine Figure 3.5 in workshop machine at the Fasa B to fabricate a set of transducers based on the design and the dimensions required.

Figure 3.4: Vertical milling machine

In Figure 3.6, shown the process during the fabrication process of the transducer casing by using the vertical milling machine. The fabricating started with part1 for the set of transducers one by one and part 2, and then combined the two parts by using the square aluminum piece on the top of the transducer casing closed by the screws, which fabricated by using the drilling machine. The Figure 3.7 show the fabricated transducer casing.

Figure 3.5: Vertical milling machine during the process during of fabrication the transducer

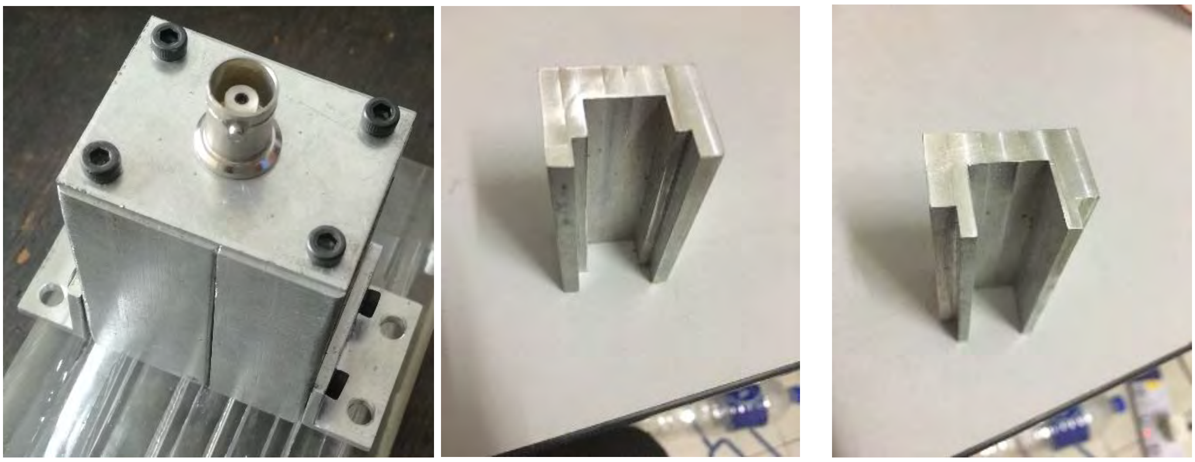


Figure 3.6: Fabricated transducer casing

3.4 Shoe with Holder Design and Fabrication

3.4.1 Shoe and holder Design

The shoe designed by using solid works based on the dimensions of the old shoe in the maintenance lab as shown in the Figure 3.7 below, the features of the shoe design to fit with the aluminum pipe for this experiment.

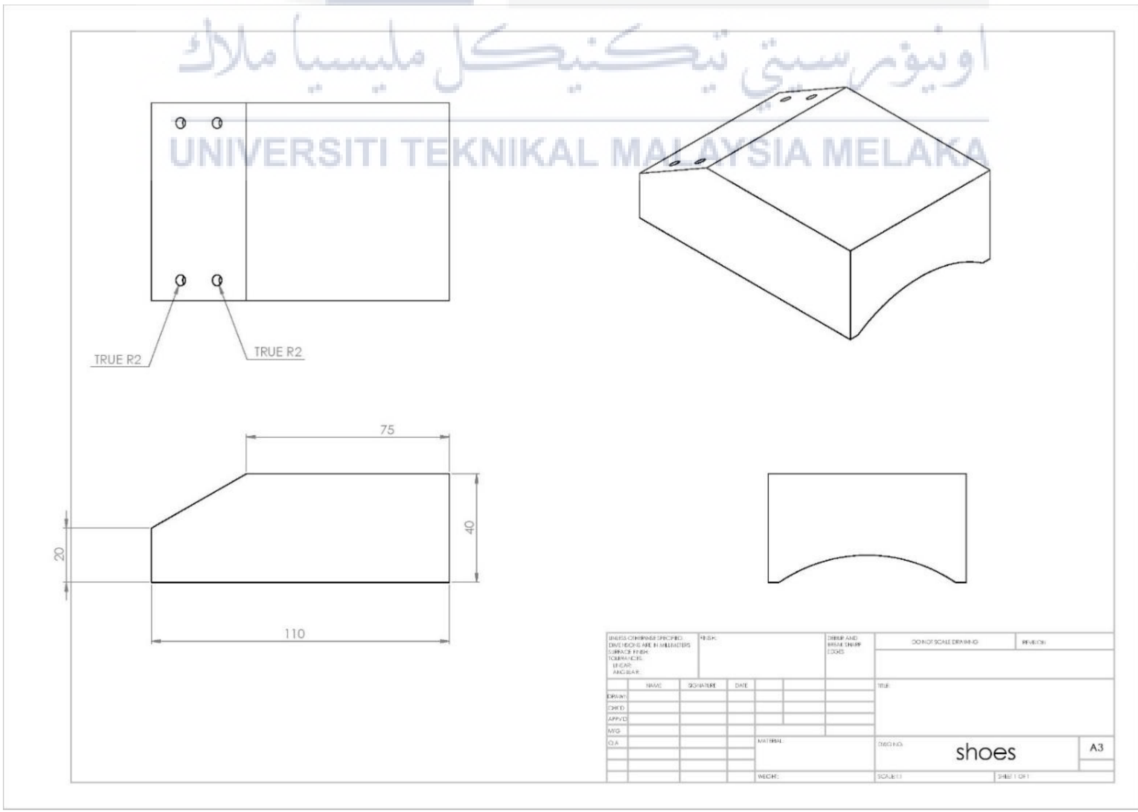


Figure 3.7: Shoe design

The holders are to hold the transducer casing with the shoe and by using the solid works designed with dimensions to be suitable with transducer casing and shoe, the Figure 3.8 below show the holders design, and the Figure 3.9 show the shoe with holder fixed together by using screws.

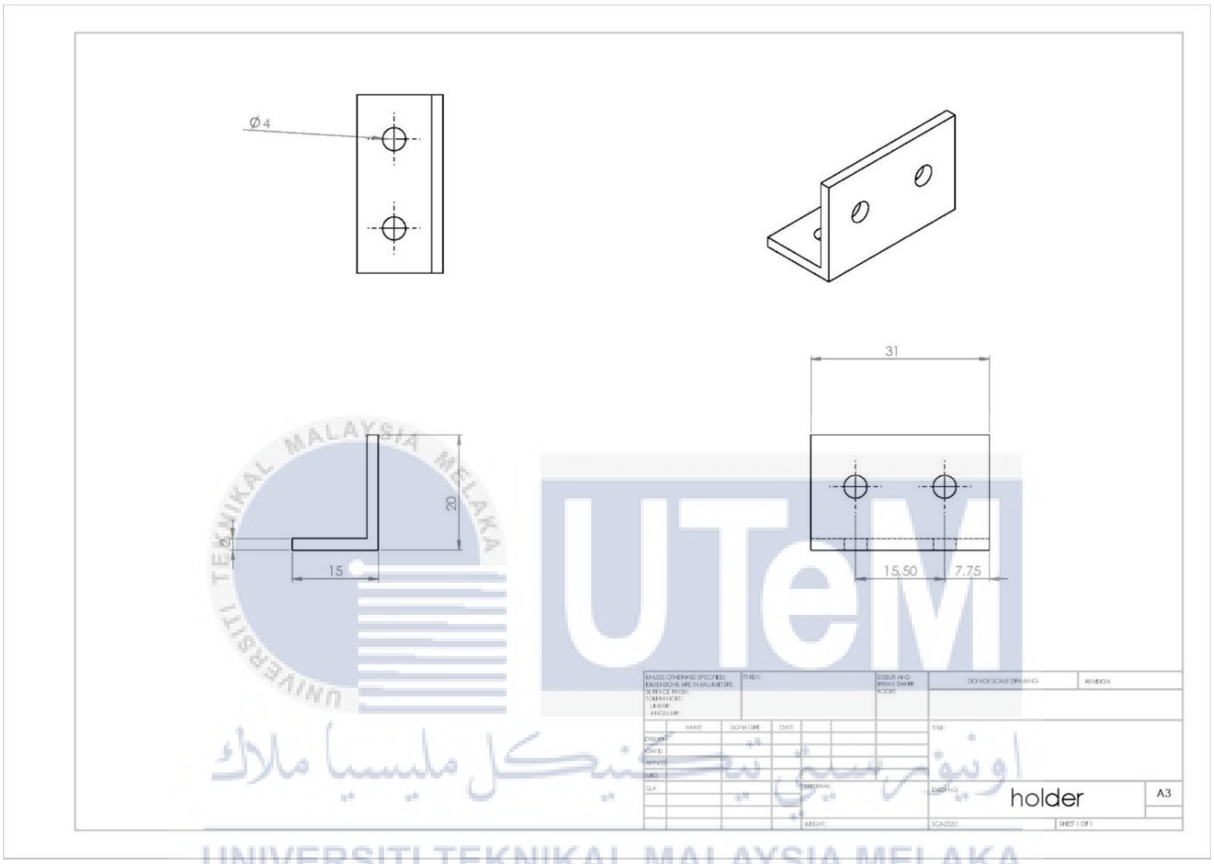


Figure3.8: Holder design

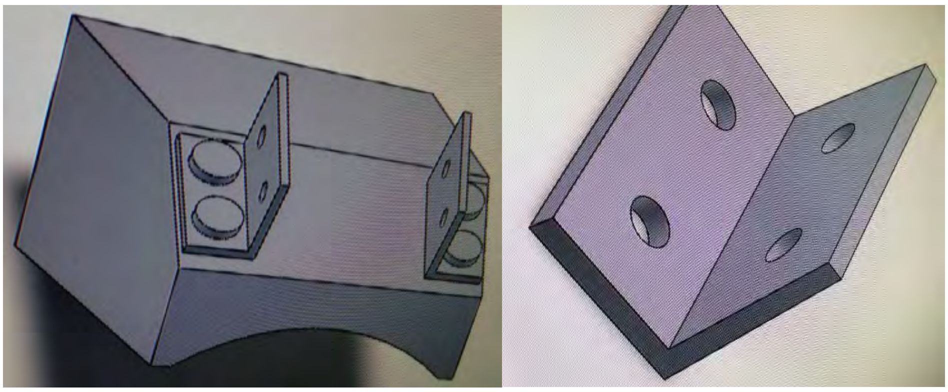


Figure 3.9: Shoe and holder assembly

3.4.2 Shoes and holders Fabrication

In the fabrication of the shoes starting by cutting the acrylic plate into 4 cubic pieces by using Professional Miter Saw as shown in Figure 3.10 below.

Figure 3.10: Cutting acrylic plates for transducer shoes

As well, by using the milling machine the shoes fabricated based on the dimensions required and the concave shape of the pipe surface as shown in the Figure 3.11 that show the process of shoe fabrication.

Figure 3.11: Cutting acrylic plates into transducer shoes on pipe

In order to reduce the reflected wave inside the shoe, grooves fabricated on the surface of the acrylic shoe by using the hand saw as shown in Figure 3.12.Such a damping material the plasticine is used to fill the grooves, the damping effect of plasticine can smoothen the signal so that any defect peak can be observed easily without any misconception of defect location.

Figure 3.12: Fabricating the grooves on the acrylic shoe

The holder fabrication is done by using the steel saw to cut the aluminum bar in to 8 block based on the dimensions that stated the design, then the milling machine is used to fabricated the shape required of the holder, Figure 3.13 show the process of the holder fabrication.

Figure 3.13: Holders fabricating processes

3.5 Defect Fabrication

In this experiment, the artificial defects fabricated on the aluminum pipe in two orientations, which are the perpendicular and oblique with 45 degree.

3.5.1 Defect Fabrication in Perpendicular Orientation

In order to carry out this experiment the artificial defect fabricated on outer the surface of pipe structure with the geometric that shown in the Table 3.1 below. The defects fabricated to one end of the pipe to evaluate the set of sensors that developed using PZT element; the defect on the pipes will be at the outer surface of pipe as shown in the Figure 3.14.

Table 3.1: Geometric of pipe

Material	Aluminum
Length	6000mm
Inside diameter	98mm
Outer diameter	110mm
Thickness	6 mm

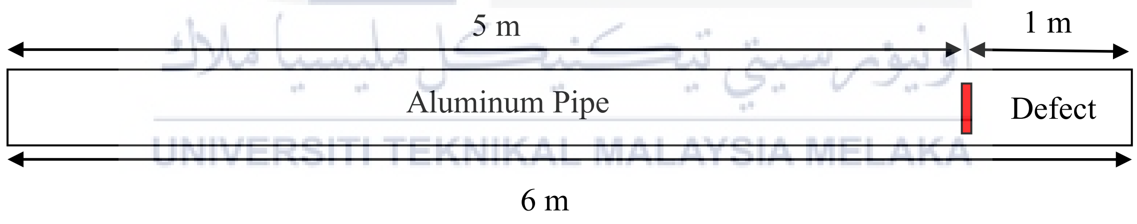


Figure 3.14: Defect location

Table 3.2 Detail dimension of the perpendicular defect that fabricated on the pipe by using File as shown in the Figure 3.15below.

Table 3.2: Dimension detail of the perpendicular defect

Length	100mm
Depth	3mm
Width	10mm
Location (from end of pipe)	1000mm

Figure 3.15: 3 mm depth defect – top view, side view

3.5.2 Defect Fabrication in Oblique Orientation

With 45 degree, the artificial oblique defect fabricated on the outer surface of aluminum pipe based on the dimension detail that shown in the Table 3.3 below, also the Figure 3.16 shows the process of the oblique defect.

Table 3.3: Dimension detail of the oblique defect

Length	100mm
Depth	3mm
Width	10mm
Location (from end of pipe)	1000mm
Degree	45

Figure 3.16: 3 mm depth oblique defect

3.6 Transducers develop

The transducer consist of three layers, the first layer is the matching layer, which is plate of aluminum with 8 mm thickness that attached directly to shoe surface. The second layer is a piezoelectric sensor as transmitter and receiver of the guided wave signal and the third layer is the backing material, the Plasticine is used inside the transducer to cover the three layers in order to reduce the noise wave when the guided wave is propagating. Figure 3.17 shows the developed transducer with tree layers.

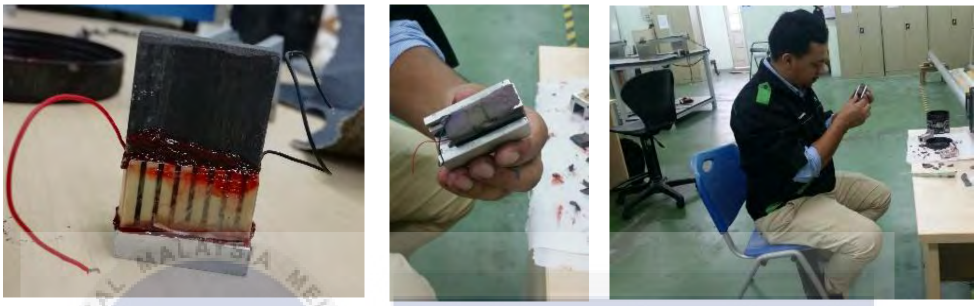


Figure 3.17: Transducer developed

3.7 Transducers, Shoes and Pipe Setup

The fabricated transducer casing and acrylic shoes attached to the outer surface of pipe using an external frame made from wood. The wood frame used to hold the multiple transducers and shoe on the surface of the pipe, in order to reduce the nose wave to diagnose the defect echo easily the plasticien used to cover the front of pipe and the transducer as shown in Figure 3.18.

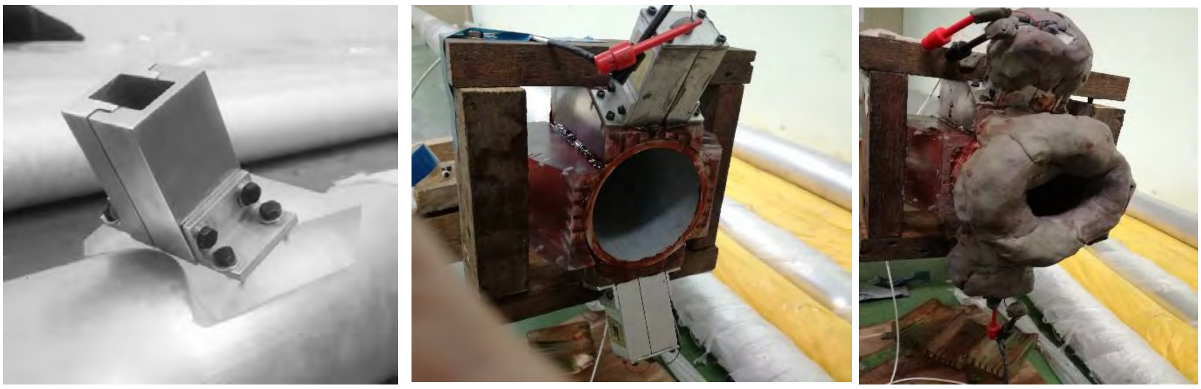


Figure 3.18: Transducers with shoes and pipe setup

3.8 Materials Properties

In the Table 3.4 below the properties of the material of the structure inspection in this research of experiment, the pipe made from aluminum.

Table 3.4: Properties of Aluminum

Material	Density (ton/mm^3)	Poisson's Ratio	Young's Modulus (MPa)
Aluminum	2.8 x 10^{-9}	0.33	70 x 10^3

As mentioned earlier, the dimension of the pipe is 6 m long, 6 mm thick while the outer and inner diameter are 110 mm and 98 mm, respectively. The cross section of the pipe with its dimension depicted in Figure 3.19while Figure 3.20 shows the length of the pipe.

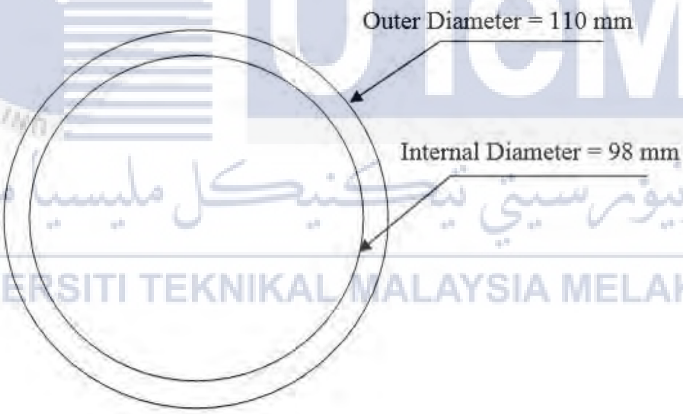


Figure 3.19: Cross section of pipe

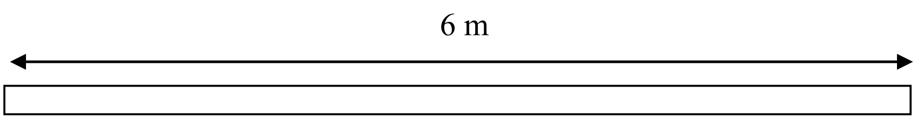
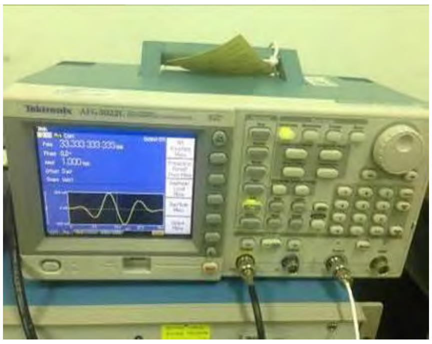


Figure 3.20: Length of pipe

3.9 Apparatus of Experiment

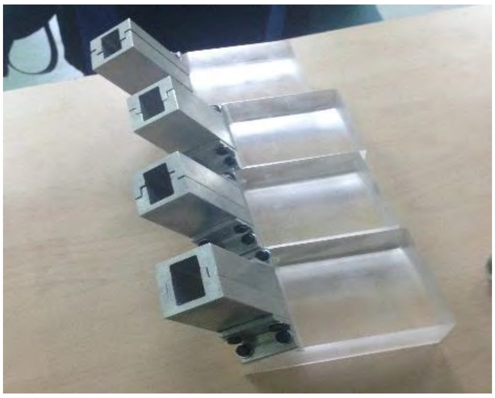
In this research, the apparatus used listed down as in Table 3.5 with the description of their specification and function respectively. These apparatus connected based on the different system required.

Table 3.5: List of apparatus

Apparatus	Description
1. Personal Computer 	• Brand: Acer • 64-bits, 16 GB RAM, Windows 7 OS. • Used to run LabVIEW program, collecting the data, also displaying the signal obtained from cancelation process.
2. Function Generator 	• Brand: Tektronix • Model: AFG3022C • Dual channel Arbitrary/ Function Generator • Produces 25 MHz Sine Waveforms • Range of 1 mHz to 12.5 MHz Arbitrary Waveforms • Amplitude up to 10 Vp-p • Sweep and Burst ability • Display excitation and responding waves signal

3. NF High Speed Bipolar Amplifier 	• Brand: NF • Model: HAS 4052 • High speed and broad band • DC to max 10MHz • Capability to supply high voltage and high power. • Output range of maximum 200Vpp • Able to drive a capacitive load and inductive load like PZT component.
4. Transducer 	• Made of PZT elements. • Sensor for non-destructive testing. • Transmit and receive guided wave into medium.
5. Stanford Low Noise Preamplifier 	• Brand: Stanford Research Systems • Model: SR 560 • 4nV/√Hz input noise • 1 MHz bandwidth • Variable gain from 1 up to 50 000. • Capability of driving 10Vpp • Providing up to 200mA of ± 12 VDC • Ideal for wide range application such as low-temperature measurement and acoustic engineering.

6. Ni Data Logger 	• Brand: National Instruments, Ni • Model: Ni USB - 5133 • High Speed Digitizer(64MB) • Varied functionality using LabVIEW software. • Connection via USB, Ethernet or wireless. • Received data fro pre amplifier and transferr the data back to PC.
7. RITEC Diplexer Preamplifier 	• Brand: RITEC • Model: RDX – EM2 • Used in pulsed ultrasonic systems using an electromagnetic transducer in a “Pulse Echo” operation. • Consist of a unique resistor and diode arrangement to deliver high power RF pulses to an electromagnetic transducer and return signals from the same electromagnetic transducer are transferred to a receiver through a 20dB pre-amplifier.
8. RITEC Pulser Receiver 	• Brand: RITEC • Model: RPR-4000 • Capable of 8 kW tone burst pulse. • 100 dB gain low noise receiver. • Providing the powerful tone burst pulse to the ultrasonic testing. • High-power, 8kW • Frequency ranges: 0.05 to 0.5 MHz and 0.25 to 2 MHz

9. Shoe & Casing 	• Made up from acrylic. • To produce the excitation of L(0,2)-mode. • To reduce mechanical noise ringing.
10. RITEC Pas Preamplifier 	• Brand: RITEC • Input Impedance: 50 Ohms – High Z • Gain Setting: 20dB/30dB/40dB. • Featured 1 V peak-to-peak. • Low-noise, broadband, high-impedance pre-amplifier designed to have the frequency range of 0.1 to 20 MHz.

3.10 Wave Propagation in Pipe

An interesting advantage of using GW is that the excitation of GW can be done at single location in the structure and then propagate to a long distance. Guided waves in pipes depends on the outer diameter and inner diameter surfaces in order to propagate in the pipe wall in long axial distances. The propagation of guided waves in the pipe can be in circumferential and axial directions. There are several numbers of modes of guided wave in a pipe waveguide. The selection of the suitable modes for an inspection pipe is a necessary in order to obtain high sensitivity in defect location from the guided wave inspection.

3.10.1 Snell's Law

At any angle of beam incidence defeated from the original direction of the incident beam either towards or away from normal depending on the relative velocities of ultrasound in two media. Relationship between the angle of incidence and angle of refraction is govern by Snell's law also known as Descartes's law. The formula used in order to explain the relation between incidence angles refractions when wave signal passes through boundary between two types of isotropic media like water, glass, and air. Snell's law state that the ratio of the sines of the incidence angle and the refraction angle equal to the ratio of the phase velocity in the two media, as shown in the equation (1) below, and the Figure 3.21 below illustrate the Snell's law between to media.

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{V_1}{V_2} \tag{3.1}$$

Where:

θ_1 = incident angle in first material

θ_2 = refracted angle in second material

V 1 = phase velocity in first material

V 2 = phase velocity in second material

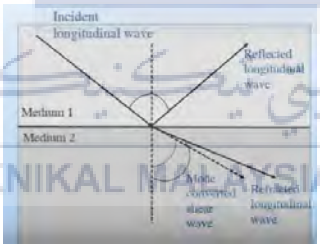


Figure 3.21: Snell's law between to media

Snell's law relates the phase velocity of the acrylic shoe and aluminum pipe, which are acrylic 2685m/s and 5410 m/s, respectively to the incident angle of the wave in the acrylic shoe. So we can obtain the incident angle for the acrylic shoe in order excite or receive L(0,2) wave mode as shown in the Figure 3.22 below by using the formula below.

$$\frac{\sin\theta_1}{\sin 90} = \frac{2685\ m/s}{5410\ m/s}$$

$$\theta_1 = \sin^{-1}\left(\frac{2685}{5410}\right) = 30^\circ$$

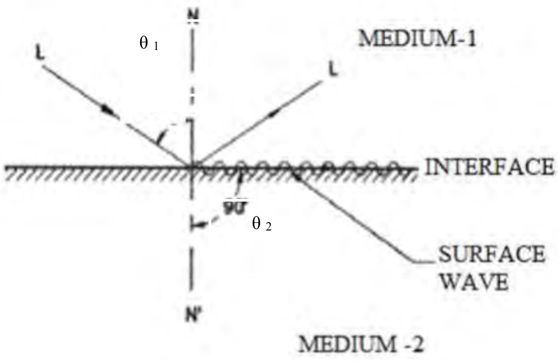


Figure 3.22: Incidence angle

3.11 Dispersion Curve and Mode Selection

Dispersion curve in this experiment for the aluminum pipe depends on the materials and the thickness of the pipe, the dispersion curve plotted in order to obtain the information regarding the modes of propagation in the pipe. The dispersion curve consist two graphs of phase velocity vs frequency and group velocity vs frequency as shown in Figures 3.23 and 3.24, respectively. The phase velocity in the dispersion curves illustrate the velocity of the harmonic cycles wave in the orientation of the propagation in pipe, they giving useful information regarding the wave speeds of single tones also the wavelengths for the modes. The group velocity from dispersion curves illustrate the velocity in which finite time wave packets travel; they can use for calculation of wave travel times and from this calculation we can identify the defect location in the pipe.

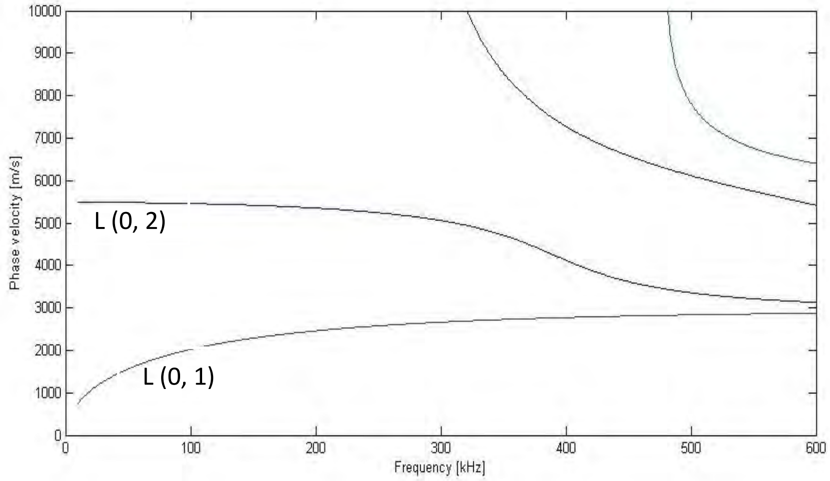


Figure 3.23: The phase velocity vs. frequency curve of 6 mm aluminum pipe

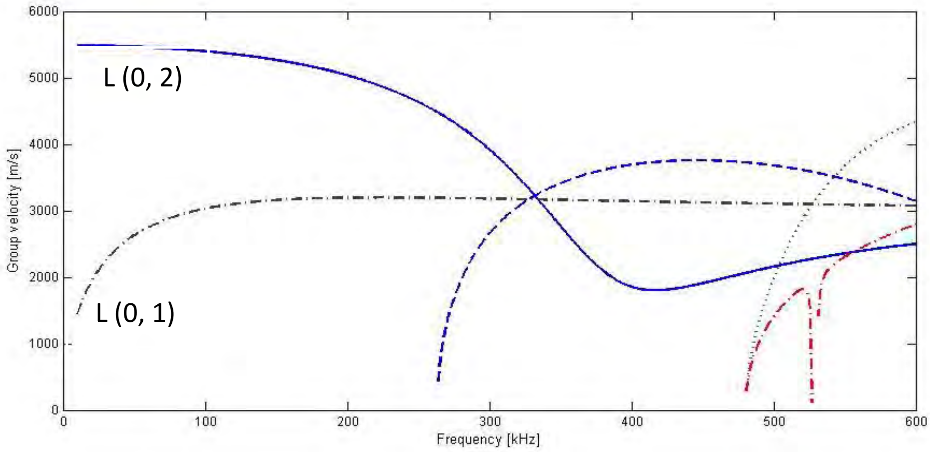


Figure 3.24: The group velocity vs. frequency curve of 6 mm aluminum pipe

3.11.1 Mode Selection

The selected mode is an axisymmetric mode, which is the longitudinal L (0, 2) mode for this experiment at three different frequencies 80 kHz, 90 kHz, 100 kHz 110 kHz, 120 kHz, 130 kHz, 140 kHz and 150 kHz. In addition, from the graphs above for the L (0, 2) mode at 100 kHz, the phase velocity is 5410 m/s and the group velocity is 5380 m/s. The characteristics of the L (0, 2) mode is it can achieves 100% of the pipe wall coverage where it is axisymmetric also has a near constant mode shape throughout the wall thickness at different frequencies used. This enhance that any defects in any position of the pipe can be identified. Moreover, The L (0, 2) mode known non-dispersive frequency regimes at low frequencies. The low frequencies suffer little attenuation and hence it can propagate long distances without loss of strength of signal. Furthermore, the advantage of the low frequencies range is having less propagating modes in pipes compared to the higher frequency.

3.12 Schematic Diagram of Measurement System

Measurement system is the combination of the NF HAS 4052 High Speed Bipolar Amplifier, RITEC PAS Preamplifier, RITEC RDX – EM2 Diplexer Preamplifier, NI Digitizer USB - 5133, PZT sensors and computer. From the computer, the LabVIEW program control the excitation of the burst signal which pass through the NI Digitizer USB - 5133, then to function generator that will send the sine wave to the NF HAS 4052 High

Speed Bipolar Amplifier. Then, the signal will pass into the RITEC RDX – EM2 Diplexer Preamplifier before out to the transducers. The response signal then will detected by the transducer and to the Diplexer again before passing through the RITEC Pas Preamplifier before the NI Digitizer USB - 5133 and computer. The schematic diagram can be seen in Figure 3.25.

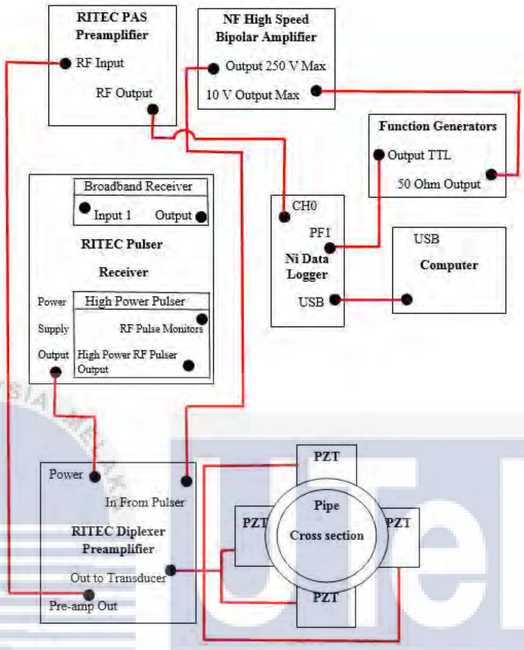


Figure 3.25: Schematic Diagram of system using NF HAS 4052 Bipolar Amplifier and RITEC Pas Preamplifier

3.13 Guided Wave Excitation in Pipe

In this experiment, the angle beam transducer used in order to generate of guided waves by pulsing a piezoelectric element on the acrylic shoe that placed on the surface of pipe. The longitudinal guided wave L (0, 2) mode induced into the pipe body and propagated along the pipe wall. When these guided waves is interact with the pipe feature as weld, pipe branch, corrosion and pipe bend they produce reflected wave to the sensors in pulse-echo mode.

3.13.1 Excitation of Longitudinal L (0, 2) Mode in Pipe

There are a many methods in order to excite the longitudinal L (0, 2) mode in pipe inspection by using angle beam transducer and one of them is circumference multiplexed. The angle beam transducer multiplexing used in order to generation of symmetrical longitudinal L (0, 2) waves in the pipe 2 angle beam transducer used as continuous transducers while the acquisition of the system is distributed uniformly in inspection pipe circumference with 180 degree as shown in the Figure 3.26 below.

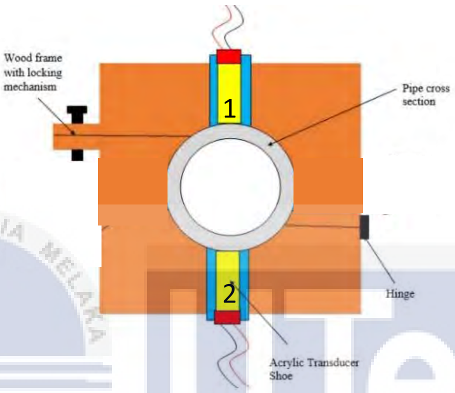


Figure 3.26: Transducer multiplexing set

Transmitters with different circumferential position provide various energy distribution, mostly angular profiles, at the same axial distance and frequency. Angle beam transducers multiplexing constructed for sending and receiving the guided waves along the pipe inspecting. In addition, it has a capacity to reduce the nose echo and cancelling the flexural mode in up and bottom position.

In angle beam transducer multiplexing, the two-angle beam transducer at the top and the bottom of the pipe surface excited to L (0, 2) along the pipe and the reflected wave to the sensor give us the data required at the specific frequency.

3.14 Defect Location

The change of acoustic impedance in the pipe due to the crack on the pipe wall that will lead to cause of reflections of guided waves from the cracks. The same transducer that used for the excitation can receive the wave reflections; the reflected waves carry information about the size and the location of the pipe defect that caused the reflections. In this, experiment the method of inspection, which use the time of arrival in order to estimate the location of the axial defect. So the location of the defect can be calculated from the wave velocity of in the pipe and the time arrival for the waves the formula below describe the how can we calculate the defect location.

Wave velocity in pipe × Time taken = Defect Location

$$\text{Location of defect} = \frac{t}{2} x V_g \qquad (3.3)$$

3.15 Signal Processing:

Signal processing in this experiment is the moving average technique will used in order to enhancement the defect echo. There several steps to perform this technique as follow.

i. Set up angle beam transducers in different positions with equal length between them and the number of position should be odd number. Figure 3.27 show three different position of transducer.

Figure 3.27: Three different position of transducer

ii. Get Signals from each transducer in every position. Figure 3.28 show the signals obtained from each transducer as expected.

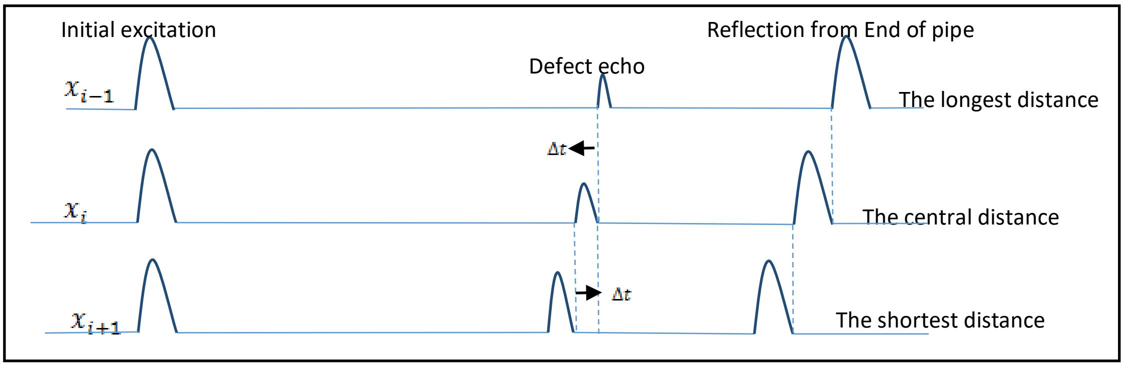


Figure 3.28: The signals obtained from each transducer as expected

iii. Doing a summation for all the signals. The defects echo that obtained will be in the same phase. Figure 3.29 show the summation of the signals.

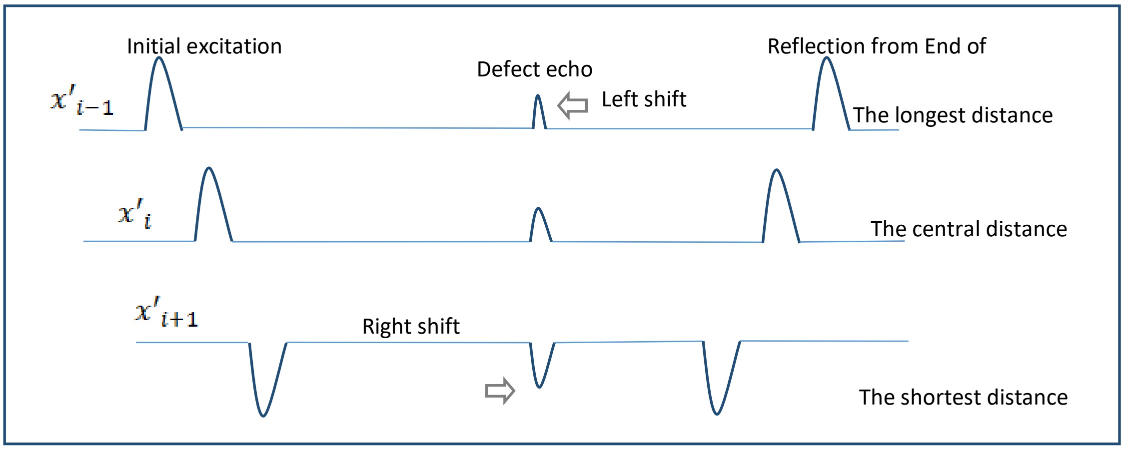


Figure 3.29: Summation of waveforms

iv. After the summation process, we will obtain the resultant wave that show the enhanced signal. The resultant wave has a larger defect echo and the initial and the reflection from the end of pipe reduced. Figure 3.30 show the enhanced signal with larger defect echo.

Figure 3.30: The enhanced signal with larger defect echo.

$$x' = \frac{1}{N}\sum_{i=1}^{j=N} x'_i \tag{3.4}$$

$$\Delta t = \frac{\Delta l}{V_{L(0,x)}} \tag{3.5}$$

3.15.1 Signal Enhancement

The angle beam transducers will excite wave into the pipe with five deferent locations, the distance between one locations to another is 14mm. So, the distance from angle beam transducers to defect location is different from one location to another, like distance from location 1 of angle beam transducers is 500 mm to the defect location, and the distance from location 5 to defect location is 444 mm.

Based on data that collected at different locations, it will use in five-point enhancement program that designed via LabVIEW which will combined all the signals conducted in five locations to produce the final enhanced signal. **Figure 3.31** below show the addition of waveform for all different distance with the frequencies that used in this experiment to detect the defect location in perpendicular and oblique locations.

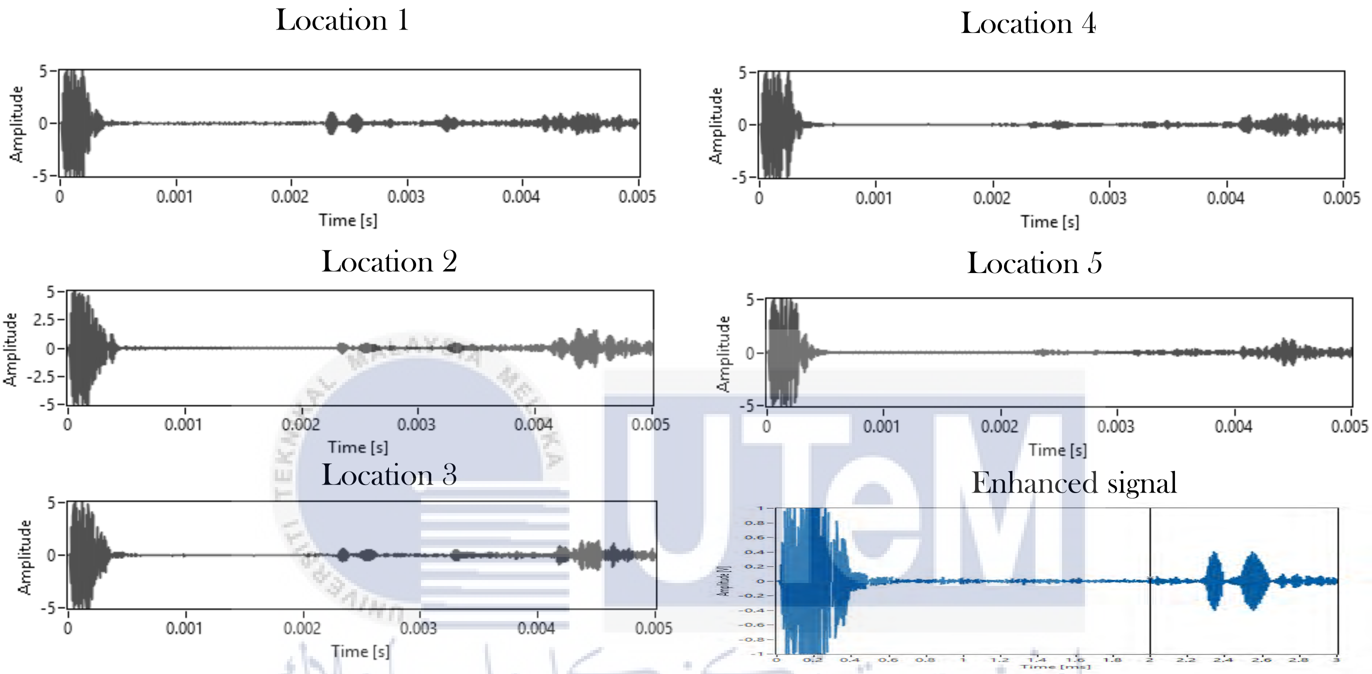


Figure 3.31: The enhancement process for waveform

3.16 Equipment Setting

The setting of the equipment as shown in the Table 3.6performed in order to get the for all frequencies 80 kHz, 90 kHz, 100 kHz 110 kHz, 120 kHz, 130 kHz, 140 kHz and 150 kHz which applied in the experiment with all five different location of angle beam transducer.

Table 3.6: Burst signal value for NF HAS 4052 High Speed Bipolar Amplifier with Stanford SR 560 Pre - Amp or RITEC Pas Pre-Amp

Parameters	Values
Number of Cycles	5
Gain	20dB
Excitation Voltage	1 Vpp

The setting for the NI Digitizer USB - 5133 also been set at certain value for the required parameters as in Table 3.7.

Table 3.7: NI Digitizer USB - 5133 setting for NF HAS 4052 High Speed Bipolar Amplifier with Stanford SR 560 Pre - Amp or RITEC Pas Pre-Amp

Parameters	Values
Sampling Rate	5 MS/s
Record length	5 ms

CHAPTER 4

RESULTS

4.1 Overview

The artificial defect that fabricated on the two different pipes, one of them is perpendicular orientation and another one is oblique orientation. These two defect detected by using guided wave propagation via angle beam transducers in order to know the ability of two angle beam transducers sensitivity to locate the defect location on the pipe. In addition, defect location can be obtain from the equation that related between group velocity and the time arrival to defect echo. The enhancement of the signal performed in this experiment to improve the sensitivity of defect screening in pipe structure by using two-angle beam transducer in top and bottom of the pipe surface using L (0, 2) mode propagation.

4.2 Singles Enhancement

The enhancement of the single that used in this experiment to improve the sensitivity of the transducer in order to detect the defect location in deferent types of defect orientation, the signal processing that developed in the LabVIEW is used to enhance the signal by from five points of data.

4.2.1Result of Perpendicular defect orientation:

By using the enhancement method in order to enhance the signals that obtain with different frequencies 80 kHz, 90kHz, 100kHz, 110kHz, 120kHz, 130kHz, 140 kHz and 150kHz, in five locations with 14mm distance between each location. Enhancement performed in to categories, first category with cancellation of L (0, 1) mode group velocity from the waveform and the second category with reduce the L (0, 2) mode group velocity from the waveform.

4.2.1.1Result of Perpendicular defect after L (0, 1) mode cancellation

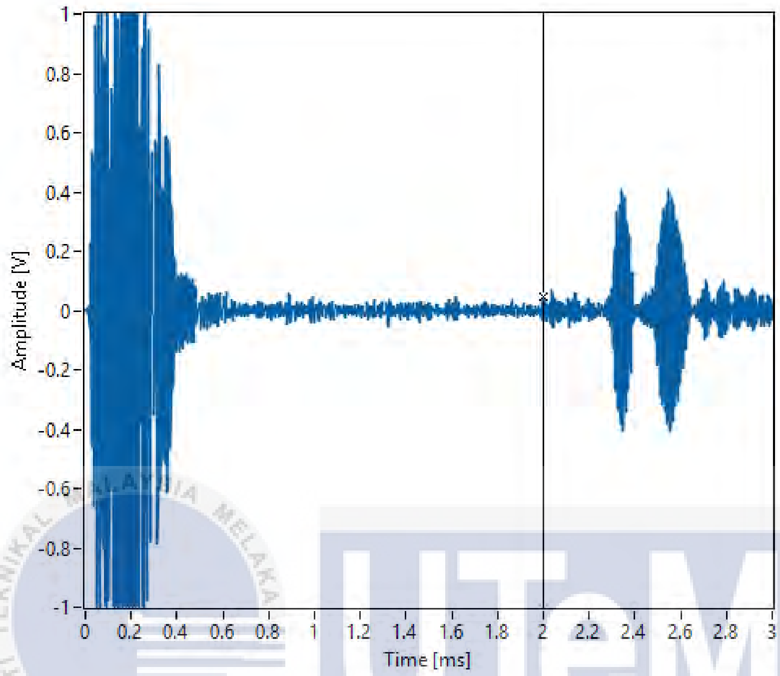


Figure 4.1: Waveform enhance at 80 kHz after L (0, 1) mode cancelation

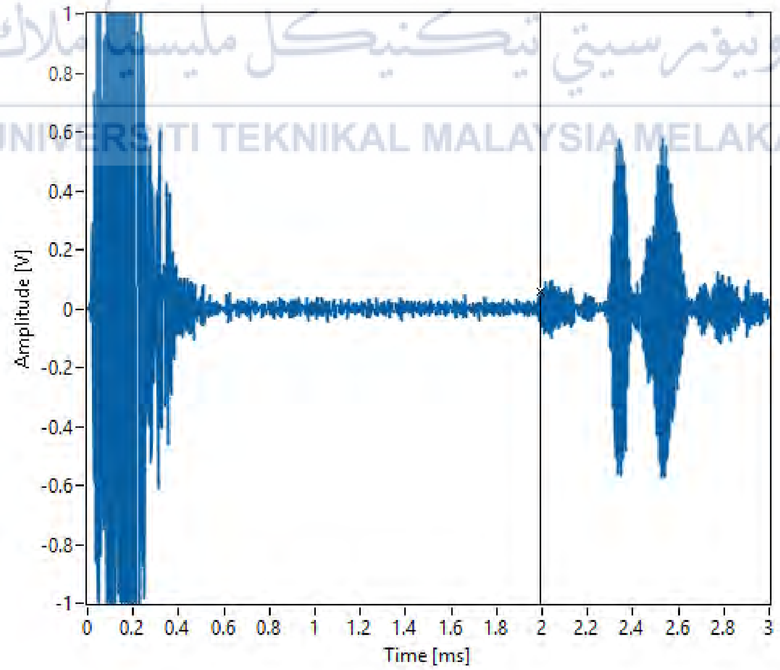


Figure 4.2: Waveform enhance at 90 kHz after L (0, 1) mode cancelation

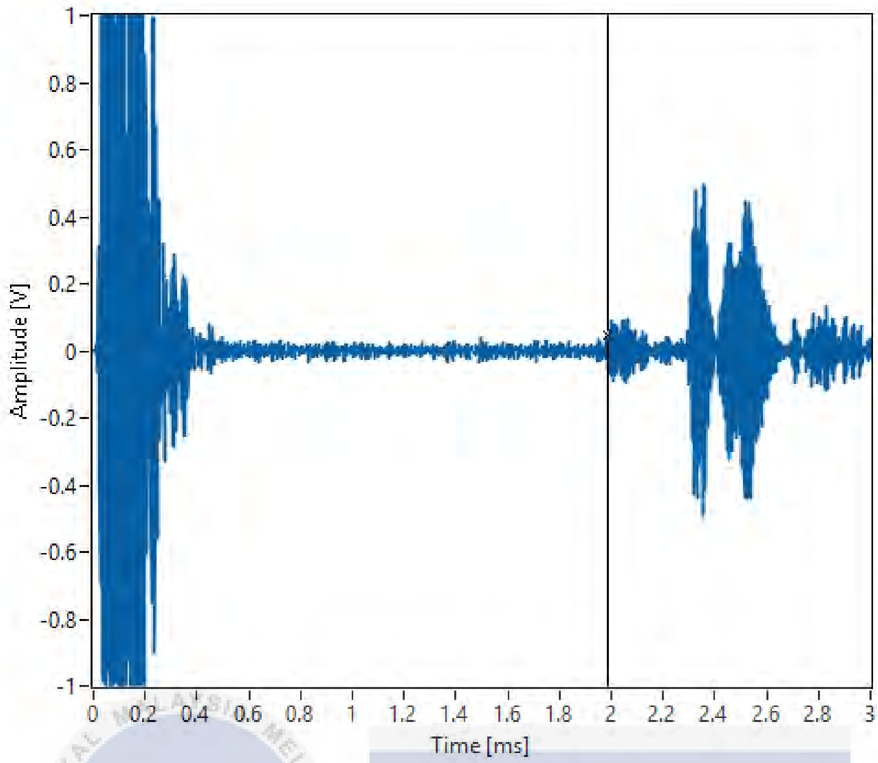


Figure 4.3: Waveform enhance at 100 kHz after L (0, 1) mode cancelation

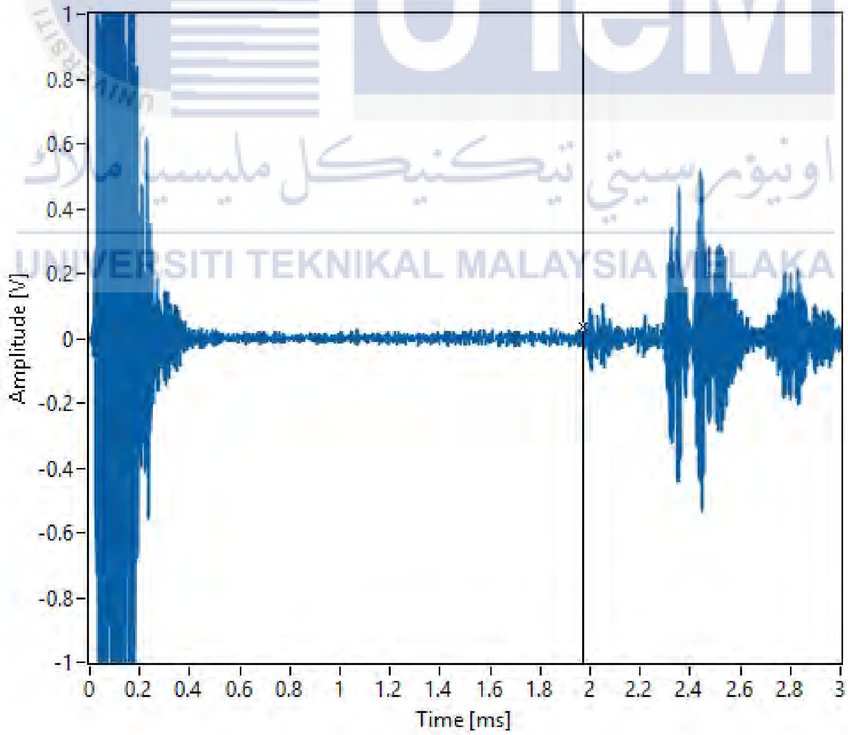


Figure 4.4: Waveform enhance at 110 kHz after L (0, 1) mode cancelation

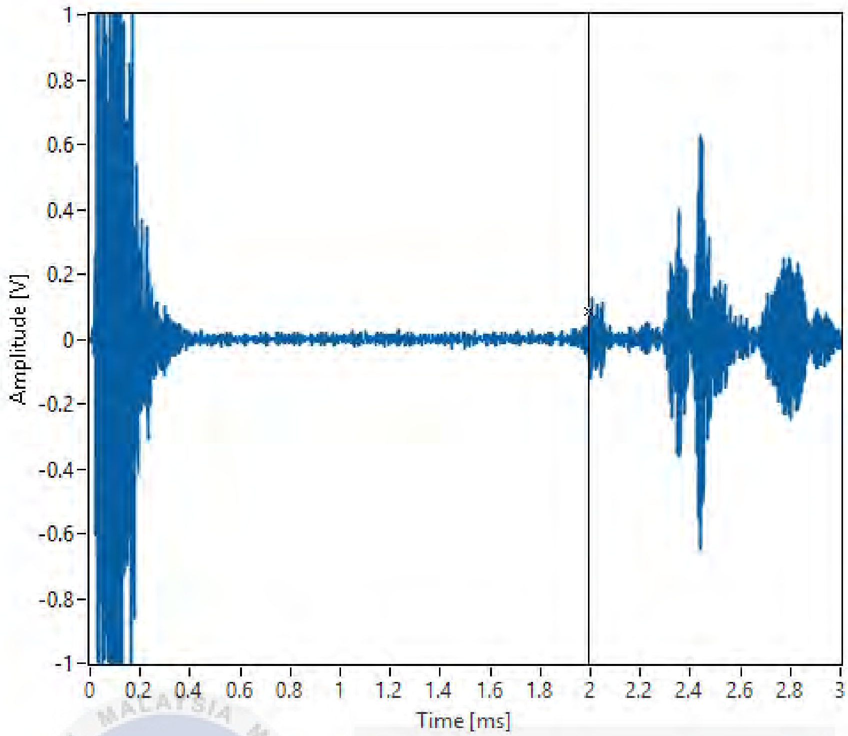


Figure 4.5: Waveform enhance at 120 kHz after L (0, 1) mode cancelation

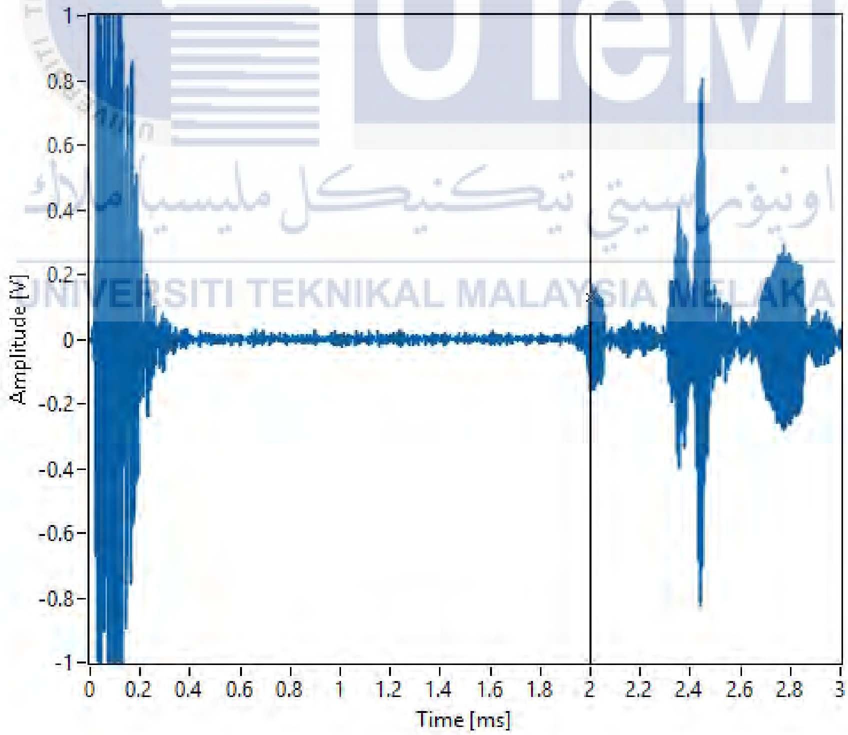


Figure 4. 6: Waveform enhance at 130 kHz after L (0, 1) mode cancelation

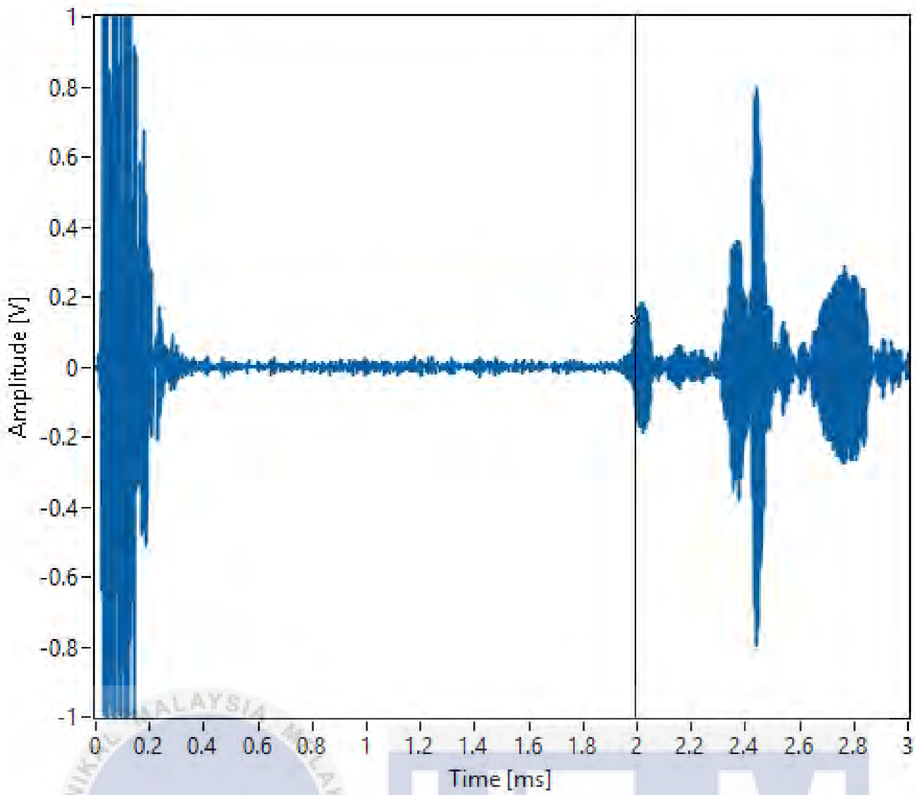


Figure 4.7: Waveform enhance at 140 kHz after L (0, 1) mode cancelation

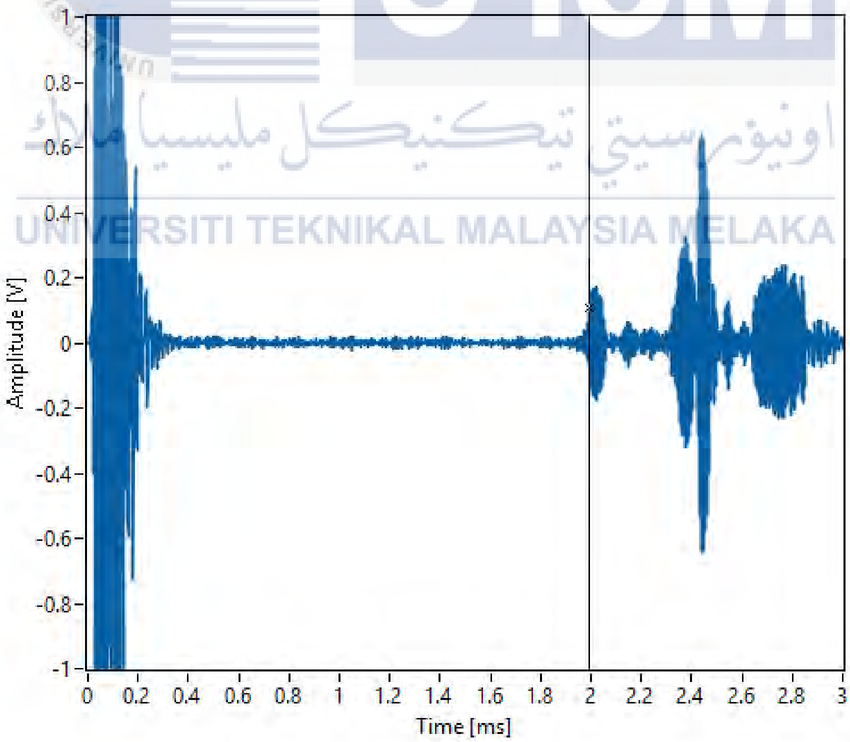


Figure 4.8: Waveform enhance at 150 kHz after L (0, 1) mode cancelation

The tables below show the information from the graphs above for enhanced waveform after L (0, 1) mode cancellation.

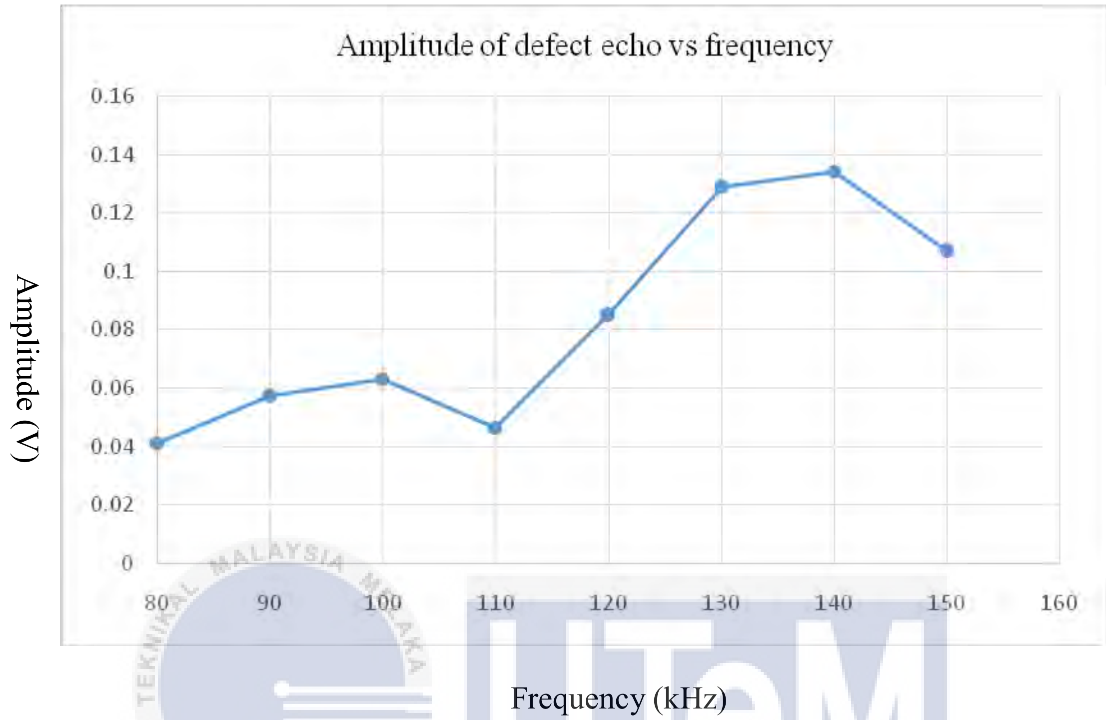


Figure 4.9: Effect of frequency excitation on the defect amplitude

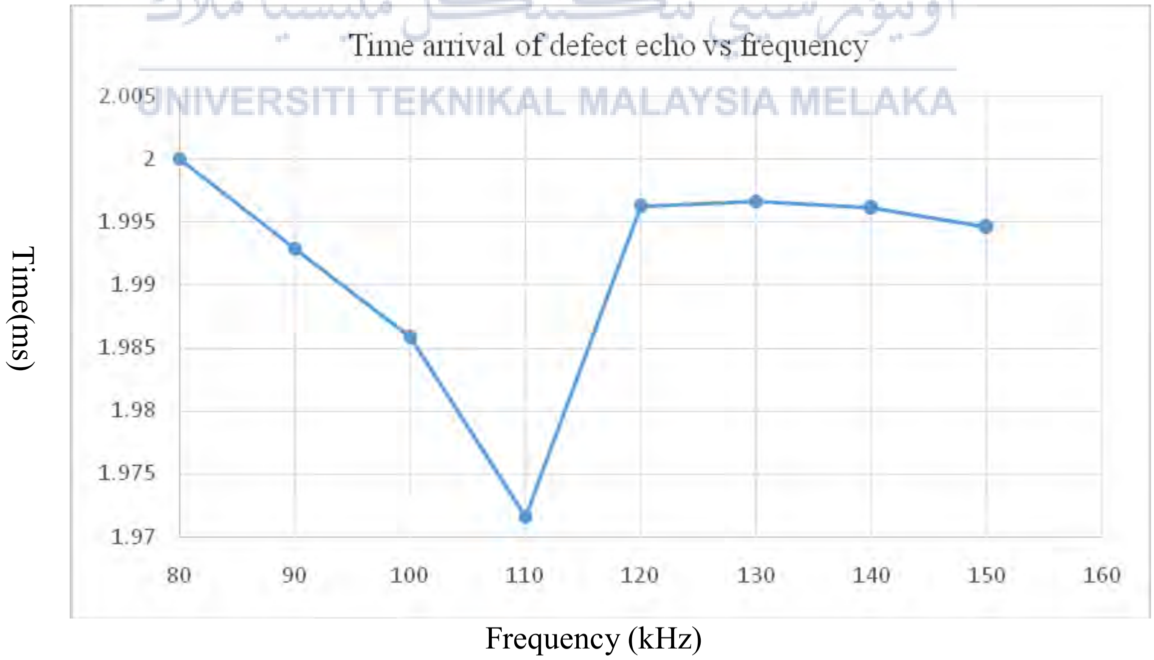


Figure 4.10: Effect of frequency excitation on the time arrival of defect echo

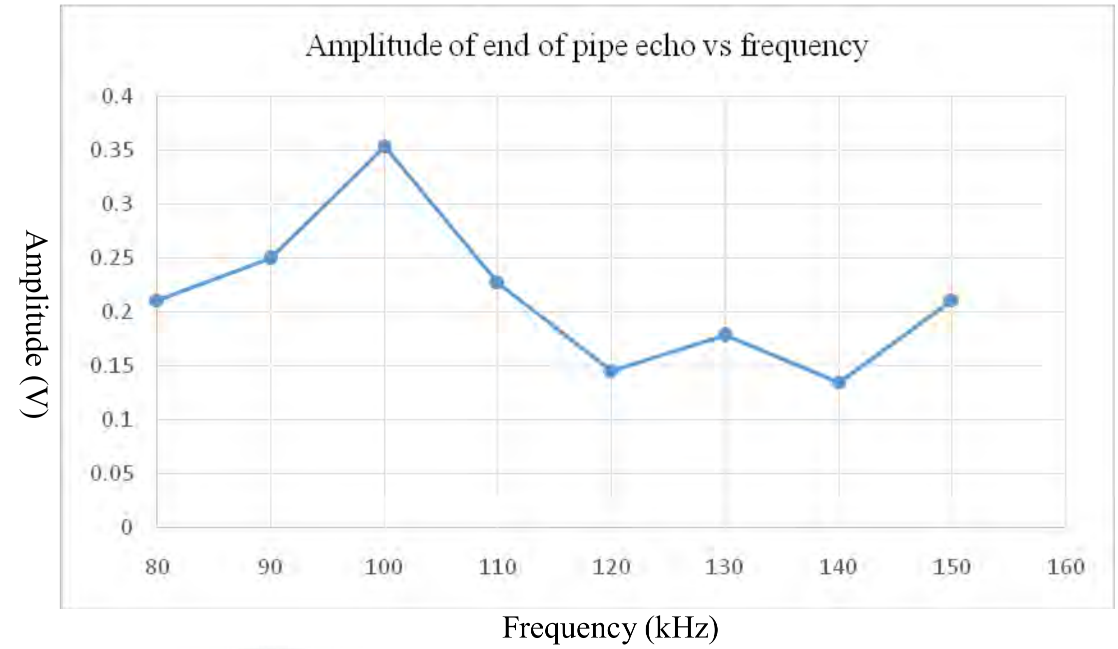


Figure 4.11: Effect of frequency excitation on amplitude of echo from the pipe end

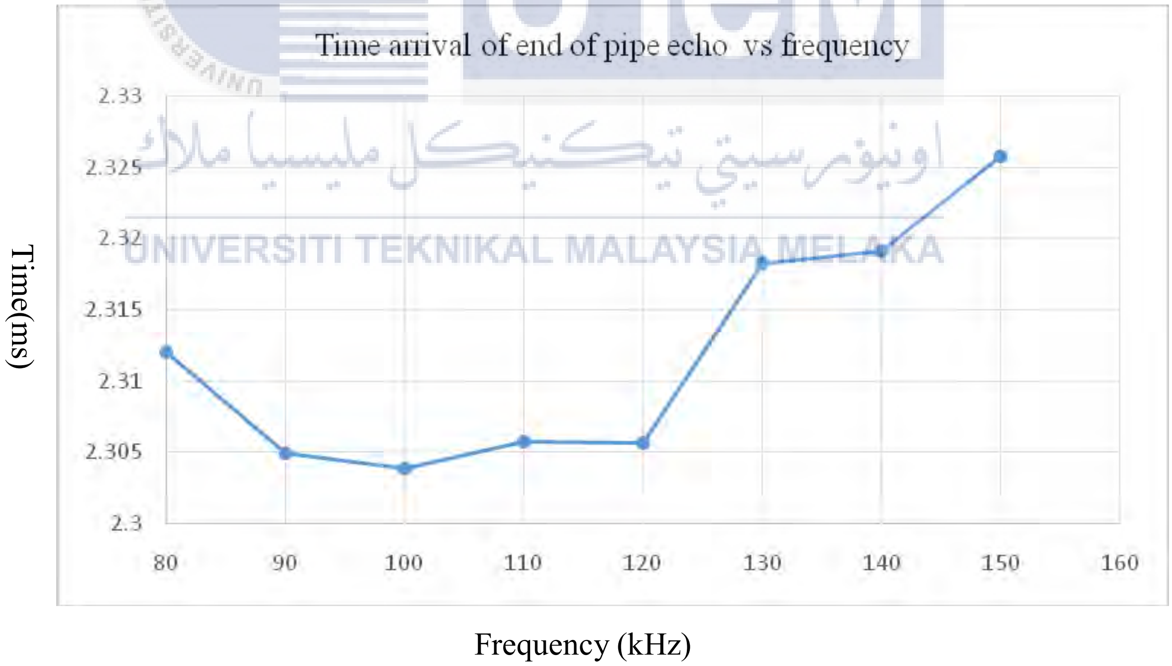


Figure 4.12: Effect of frequency excitation on time arrival of echo from pipe end

4.2.1.2Result of Perpendicular defect orientation after reduction of L (0, 2) mode:

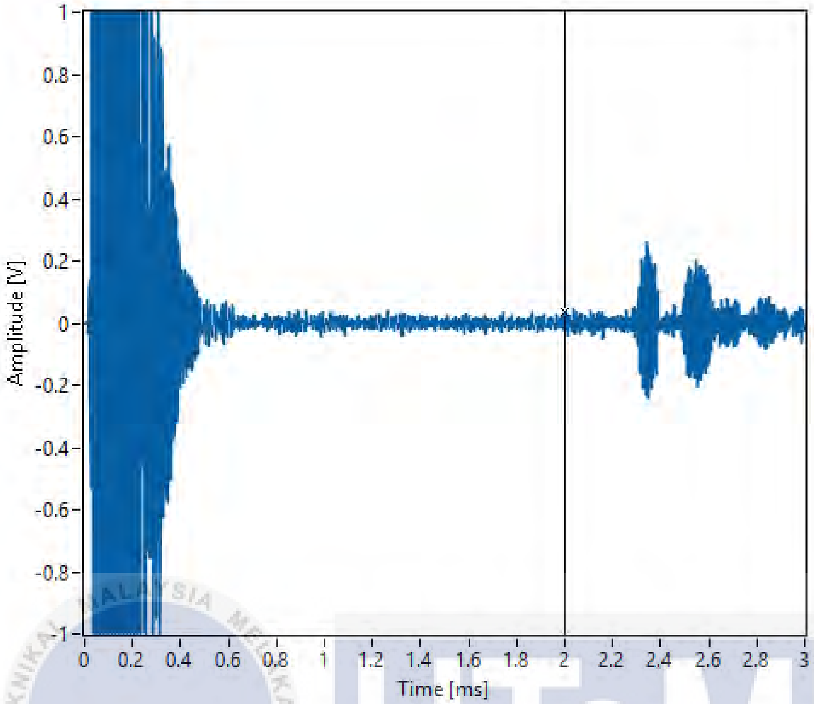


Figure 4.13: Waveform enhance at 80 kHz after reduction of L (0, 2) mode

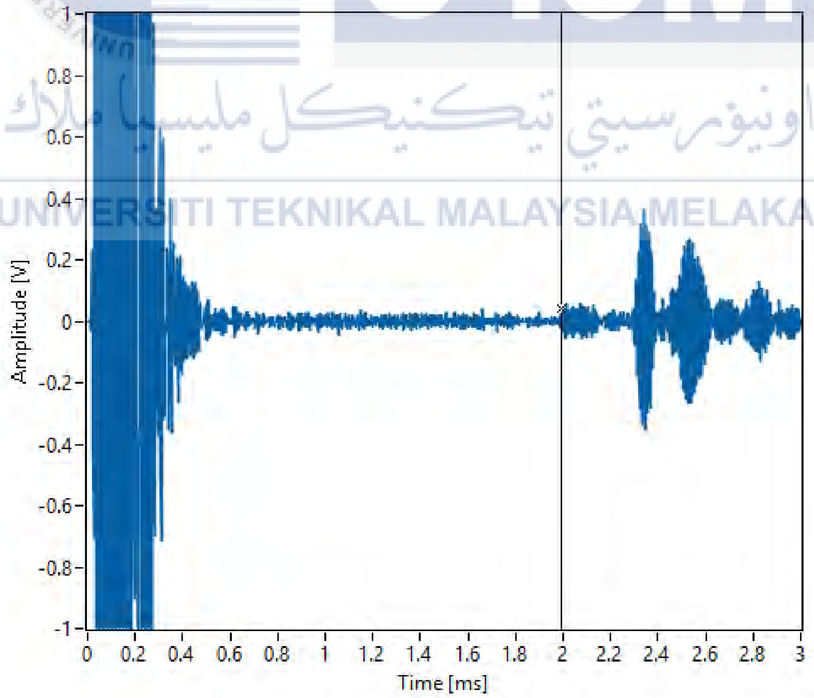


Figure 4.14: Waveform enhance at 90 kHz after reduction of L (0, 2) mode

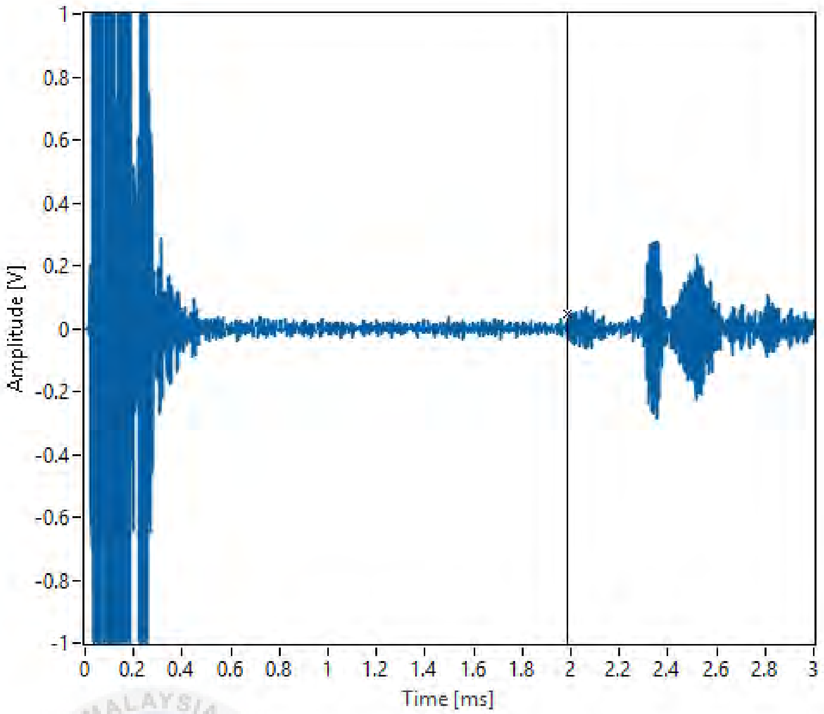


Figure 4.15: Waveform enhance at 100 kHz after reduction of L (0, 2) mode

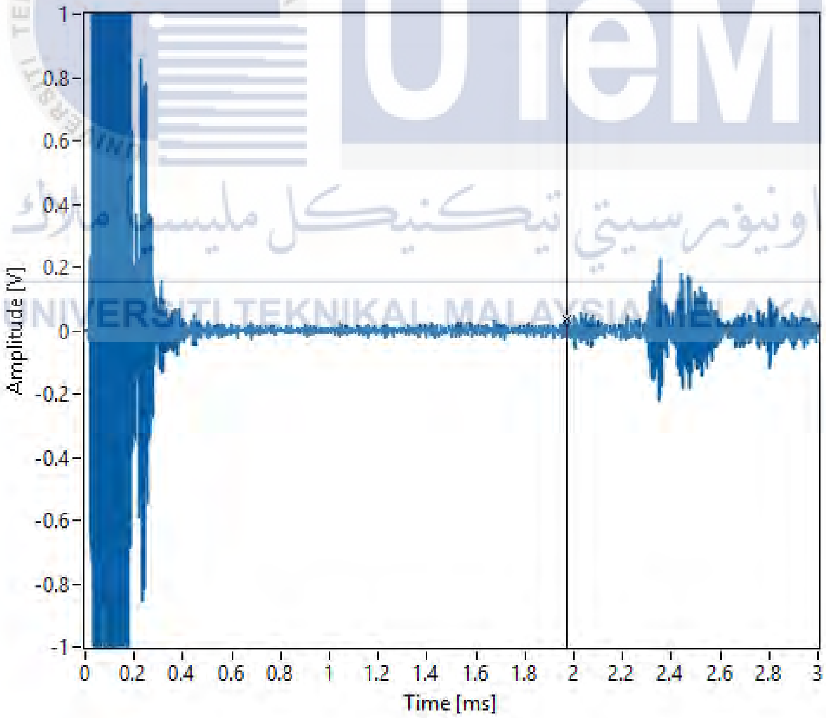


Figure 4.16: Waveform enhance at 110 kHz after reduction of L (0, 2) mode

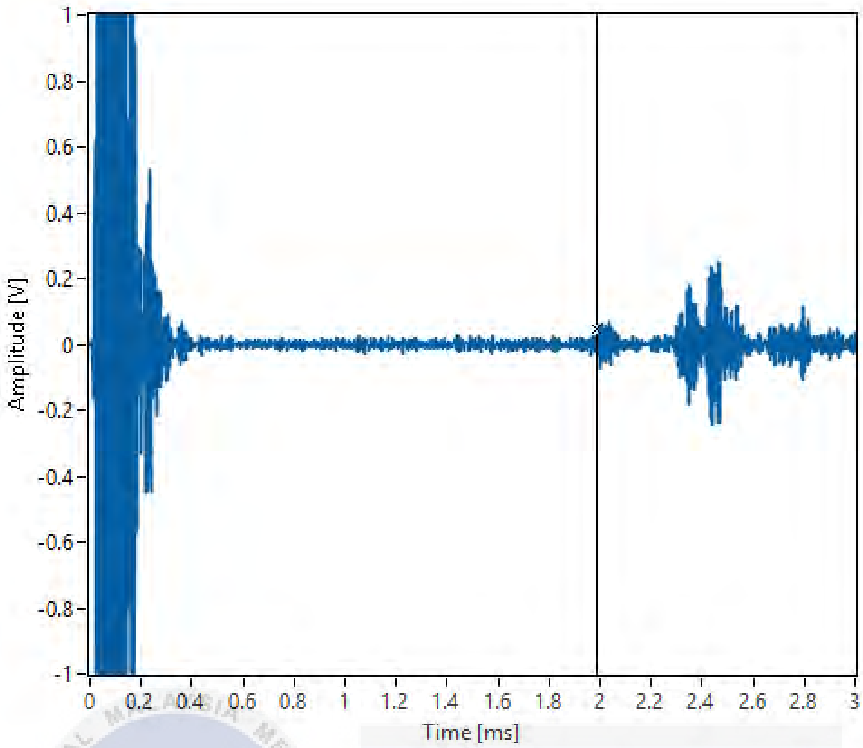


Figure 4.17: Waveform enhance at 120 kHz after reduction of L (0, 2) mode

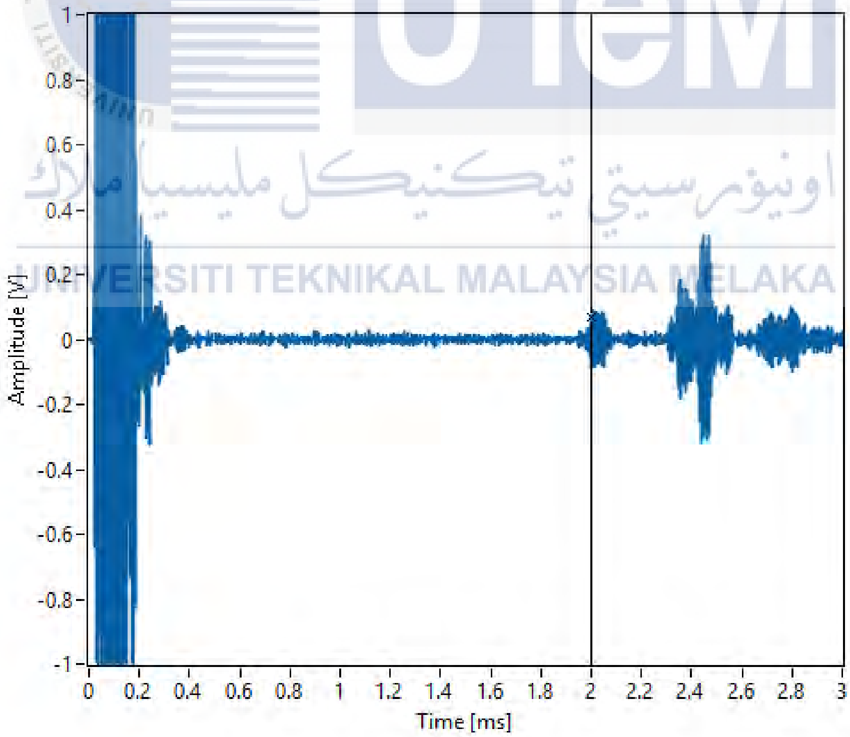


Figure 4.18: Waveform enhance at 130 kHz after reduction of L (0, 2) mode

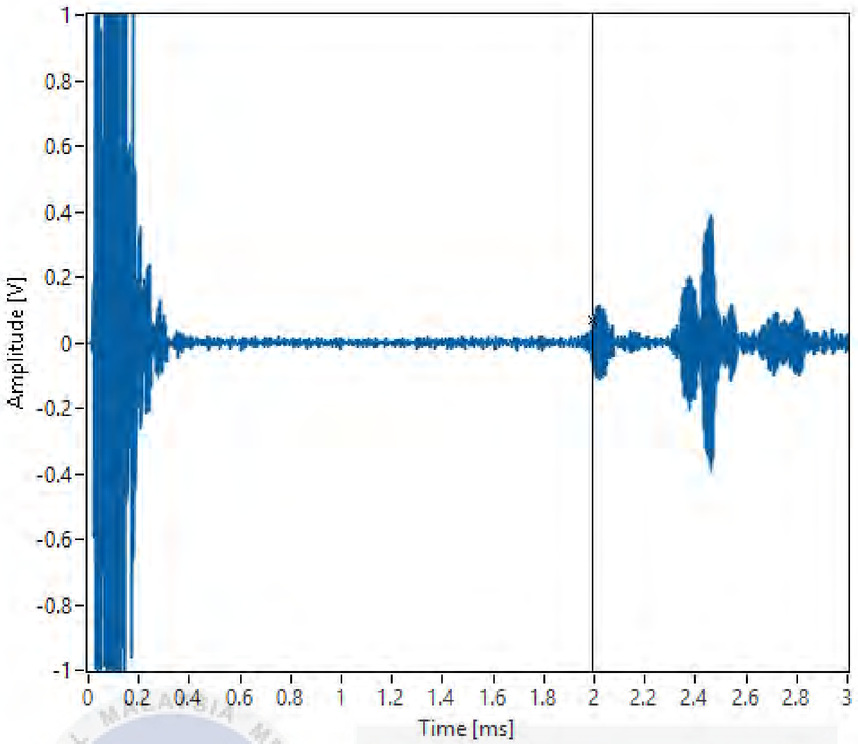


Figure 4.19: Waveform enhance at 140 kHz after reduction of L (0, 2) mode

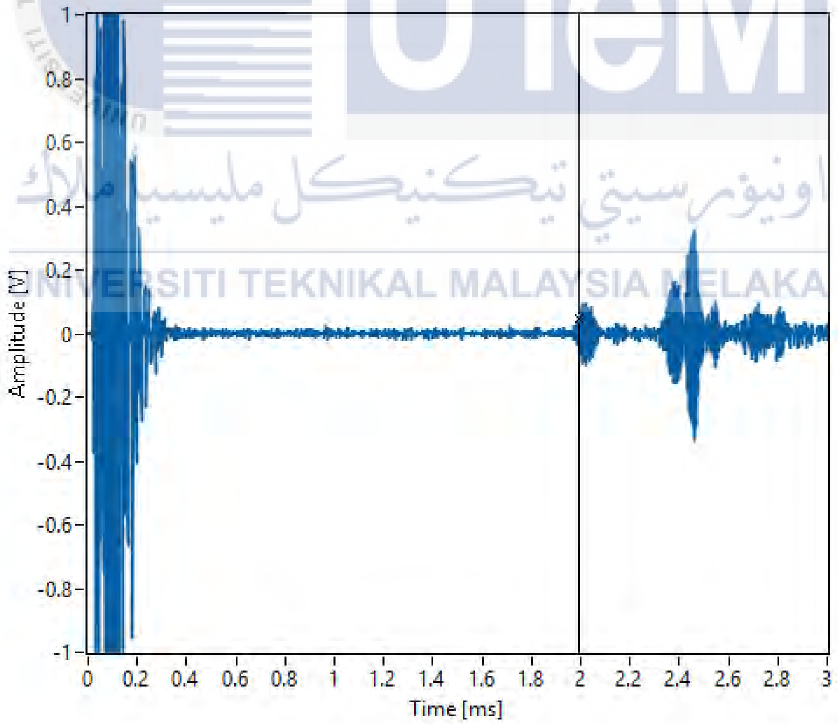


Figure 4.20: Waveform enhance at 150 kHz after reduction of L (0, 2) mode

The graphs below show the information from the enhanced waveform above for enhanced waveform after reduction of L (0, 2) mode.

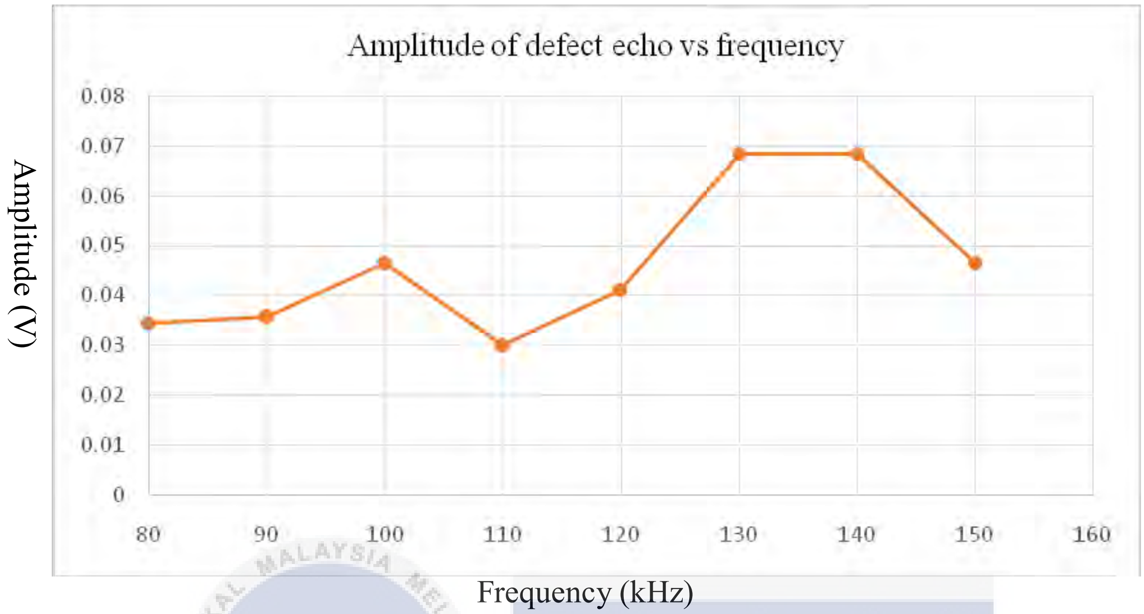


Figure 4.21: Effect of frequency excitation on amplitude of defect echo

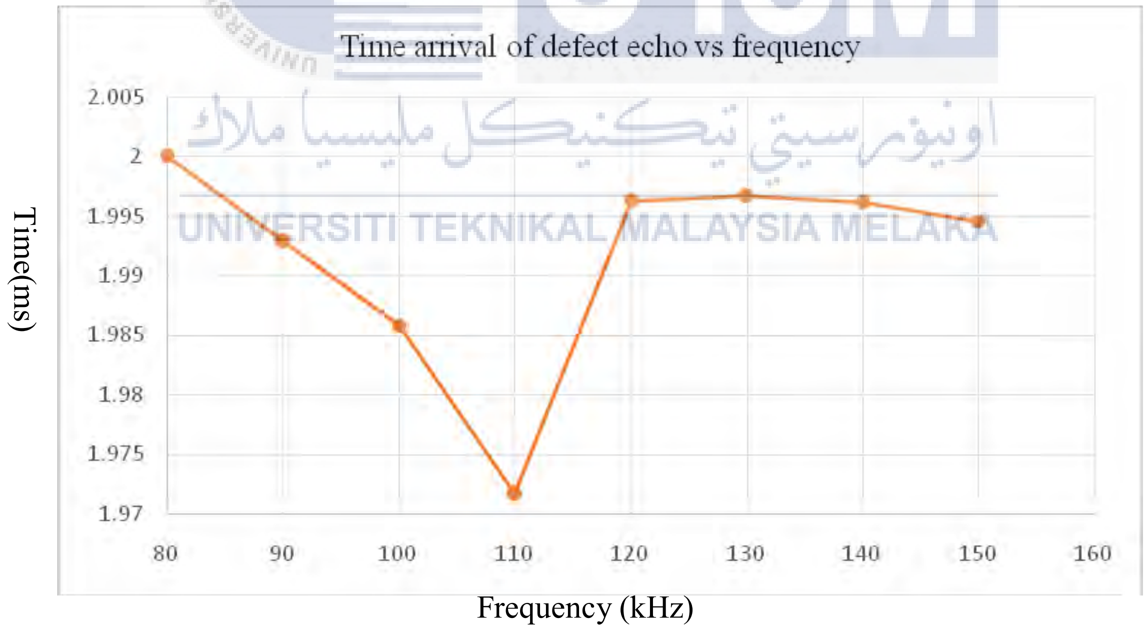


Figure 4.22: Effect of frequency excitation on time arrival of defect echo

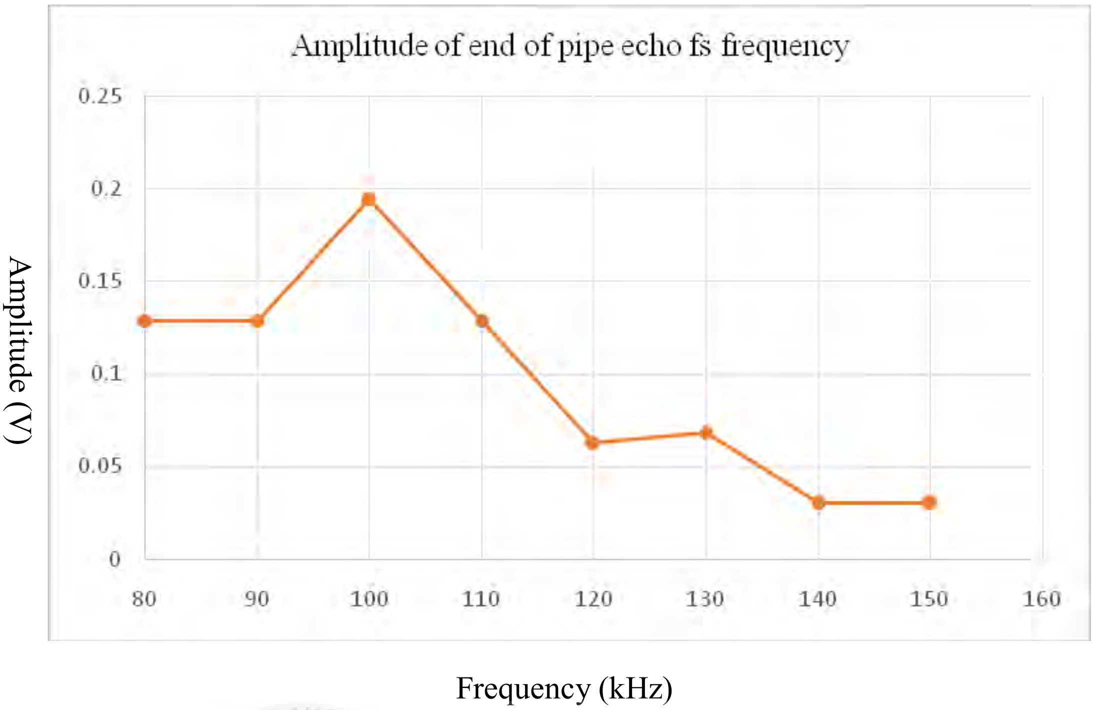


Figure 4.23: Effect of frequency excitation on amplitude of echo from the pipe end

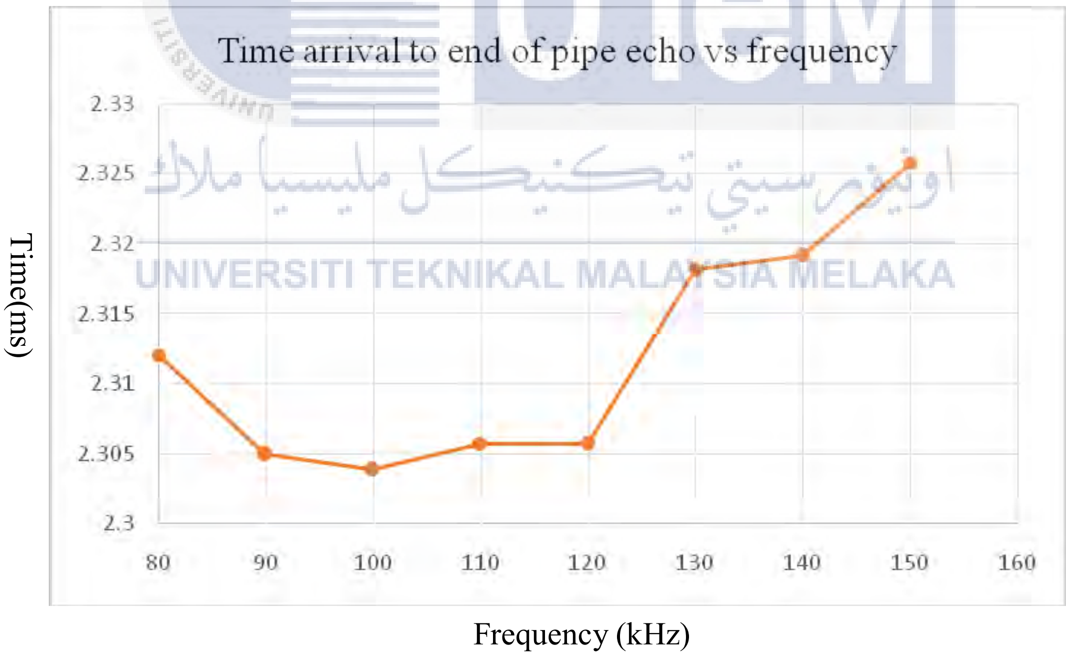


Figure 4.24: Effect of frequency excitation on time arrival of echo from the pipe end

4.2.2 Comparison of waveform of pipe with perpendicular defect after L (0, 1) mode cancellation and L (0, 2) reduction.

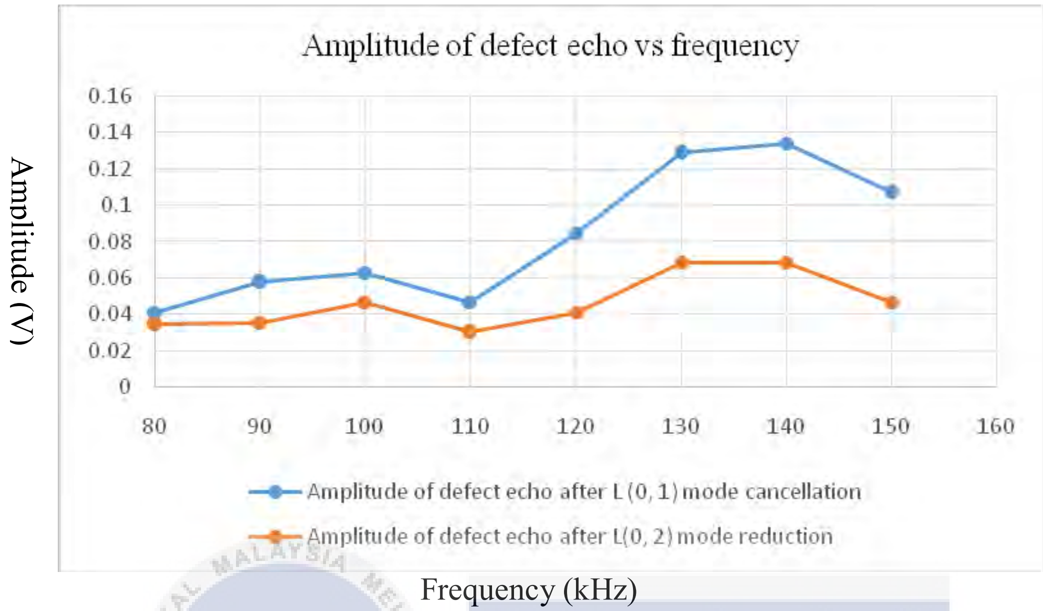


Figure 4.25: Effect comparison of frequency excitation on the defect amplitude after L (0, 1) mode cancellation and L (0, 2) reduction.

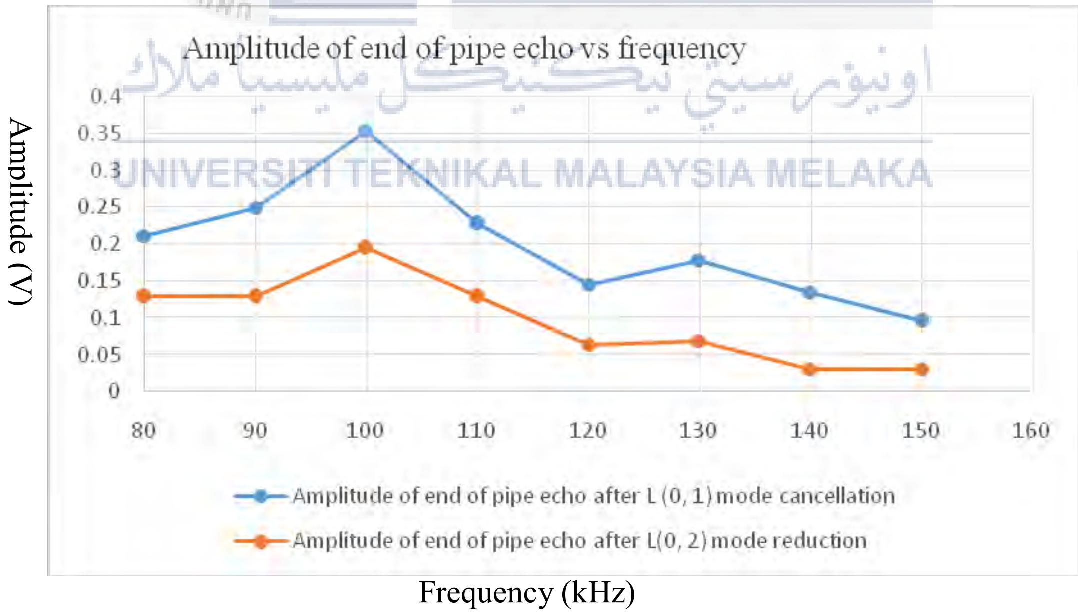


Figure 4.26: Effect comparison of frequency excitation on the defect amplitude of the pipe end after L (0, 1) mode cancellation and L (0, 2) reduction.

As shown in the above graphs in Figure 4.25 and Figure 4.26, we can obviously see the time arrival is the same in defect echo and the end of pipe echo. The difference as we see is in the value of the amplitude in waveform enhanced in all frequencies that we have used in this experiment. Waveforms enhanced after L (0, 1) mode cancellation have a higher amplitude value in defect echo also in the end of pipe echo, this is due to the L (0, 1) mode cancelled, so L (0, 2) mode that used in this experiment improved which lead to make the amplitude value higher. While, Waveforms enhanced after reduction of L (0, 2) mode have a lower amplitude value in defect echo and in the end of pipe echo, because the waveform has L (0, 1) that effect the amplitude value to be lower.

4.2.3Result of oblique defect orientation:

The enhancement method performed to do the averaging of the five waveforms that conducted in five different locations on aluminum pipe with an oblique defect using frequencies 80 kHz, 90 kHz, 100 kHz, 110 kHz, 120 kHz, 130 kHz, 140 kHz and 150 kHz. The five locations have 14mm distance between each location. Enhancement performed with cancellation of L (0, 1) mode from the waveform in order to improve the L (0, 2) in waveform Figure 4.27 to Figure 4.34 show the enhance waveform for aluminum pipe with an oblique defect.

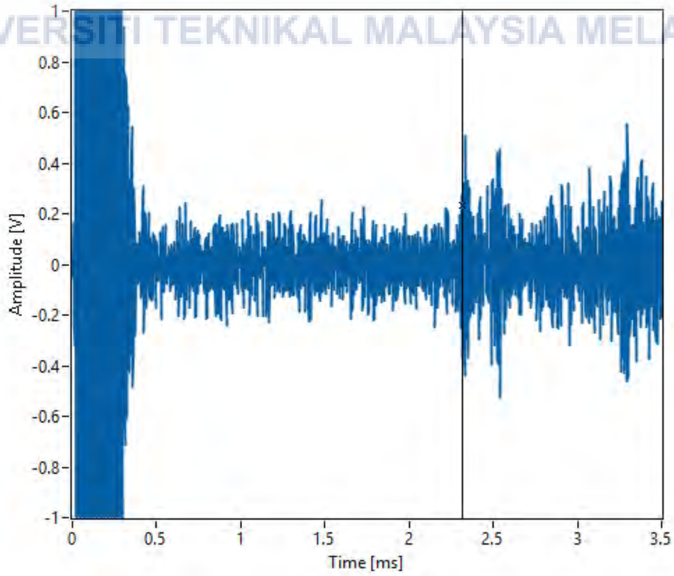


Figure 4.27: Waveform enhance at 80 kHz after L (0, 1) mode cancellation

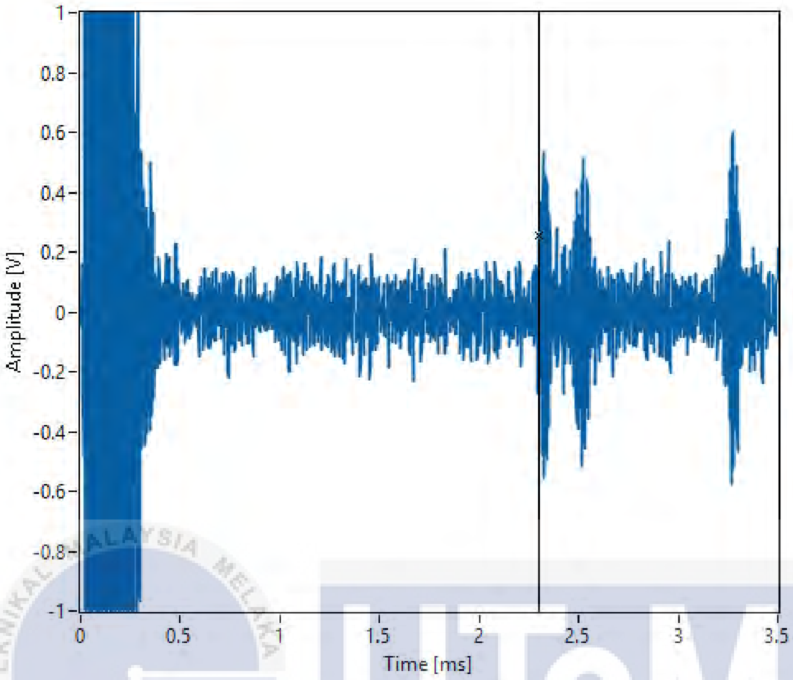


Figure 4.28: Waveform enhance at 90 after L (0, 1) mode cancellation

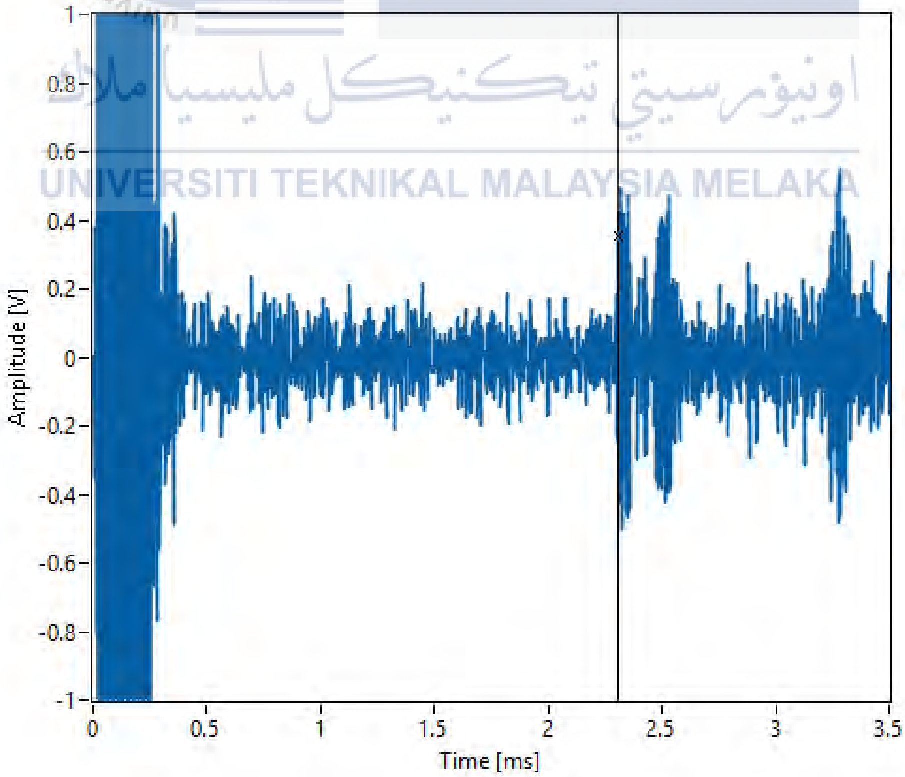


Figure 4.29: Waveform enhance at 100 kHz after L (0, 1) mode cancellation

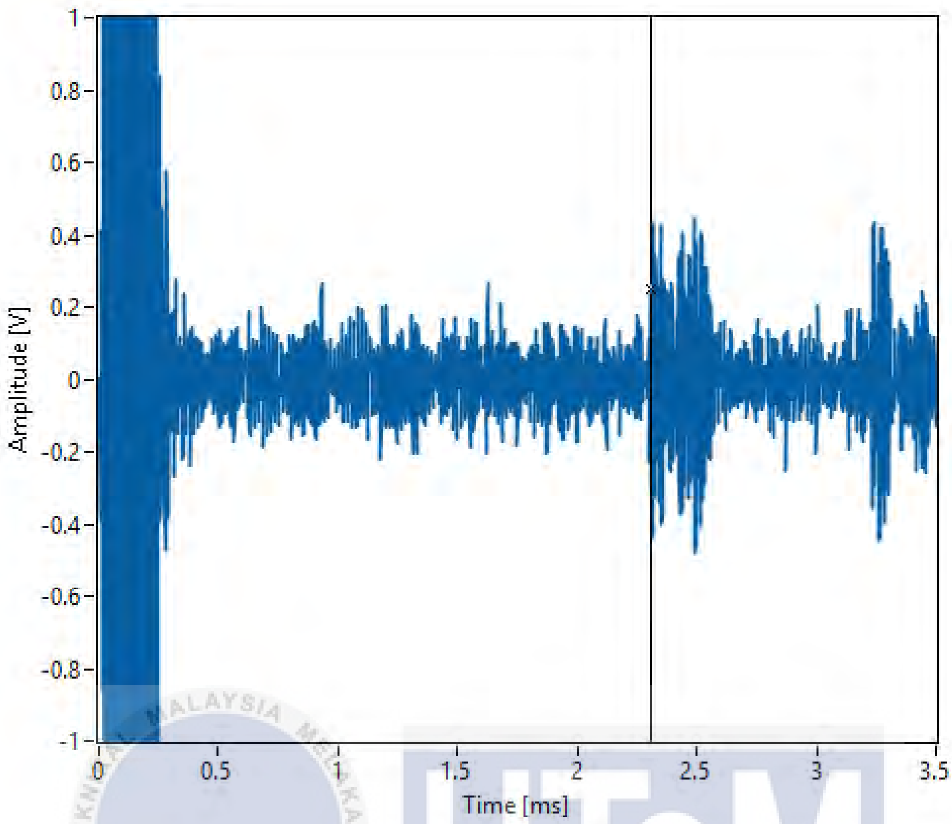


Figure 4.30: Waveform enhance at 110 kHz after L (0, 1) mode cancellation

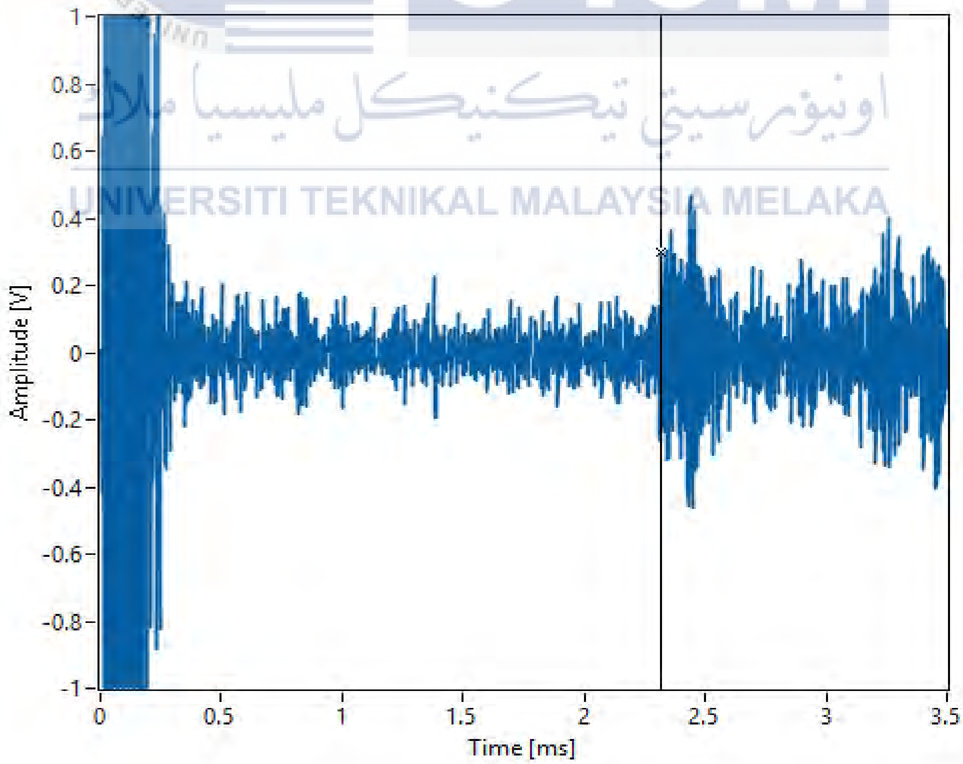


Figure 4.31: Waveform enhance at 120 kHz after L (0, 1) mode cancellation

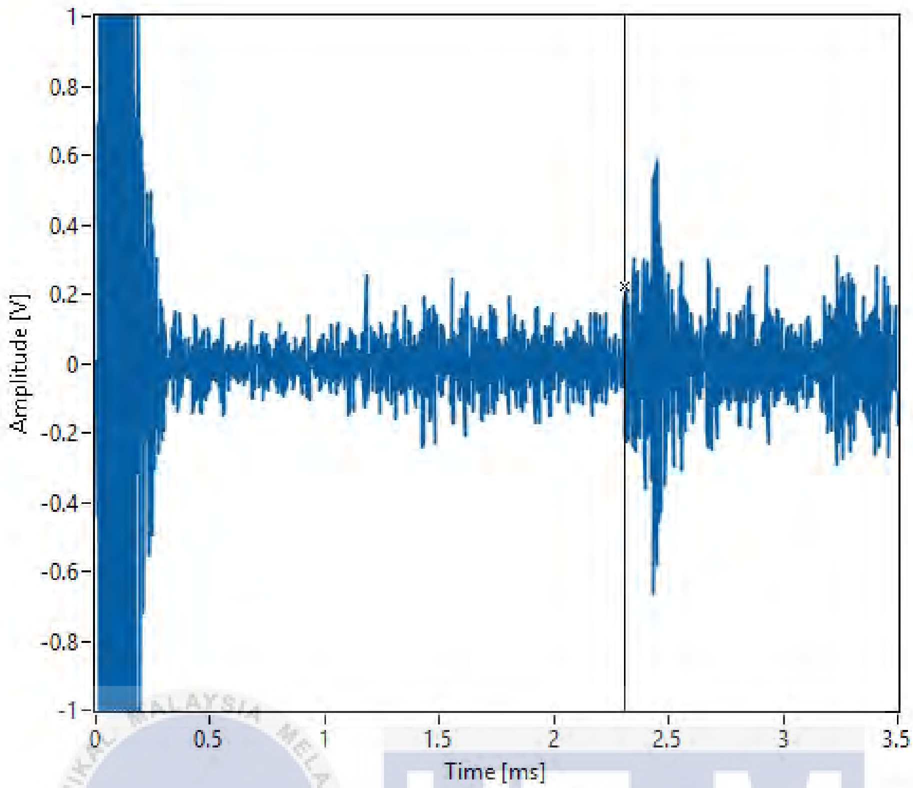


Figure 4.32: Waveform enhance at 130 kHz after L (0, 1) mode cancellation

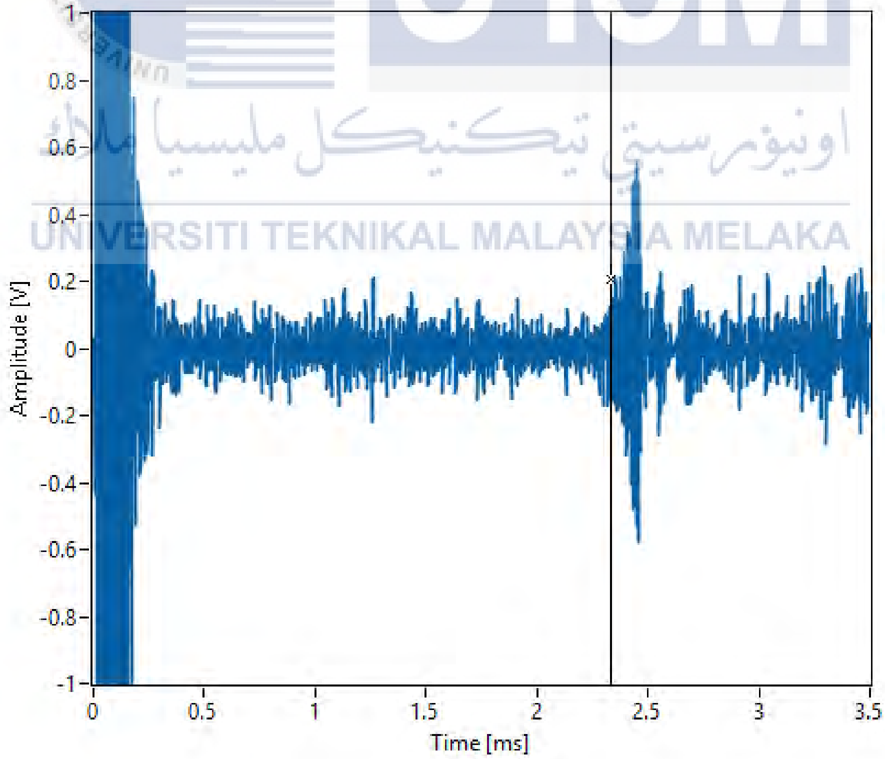


Figure 4.33: Waveform enhance at 140 kHz after L (0, 1) mode cancellation

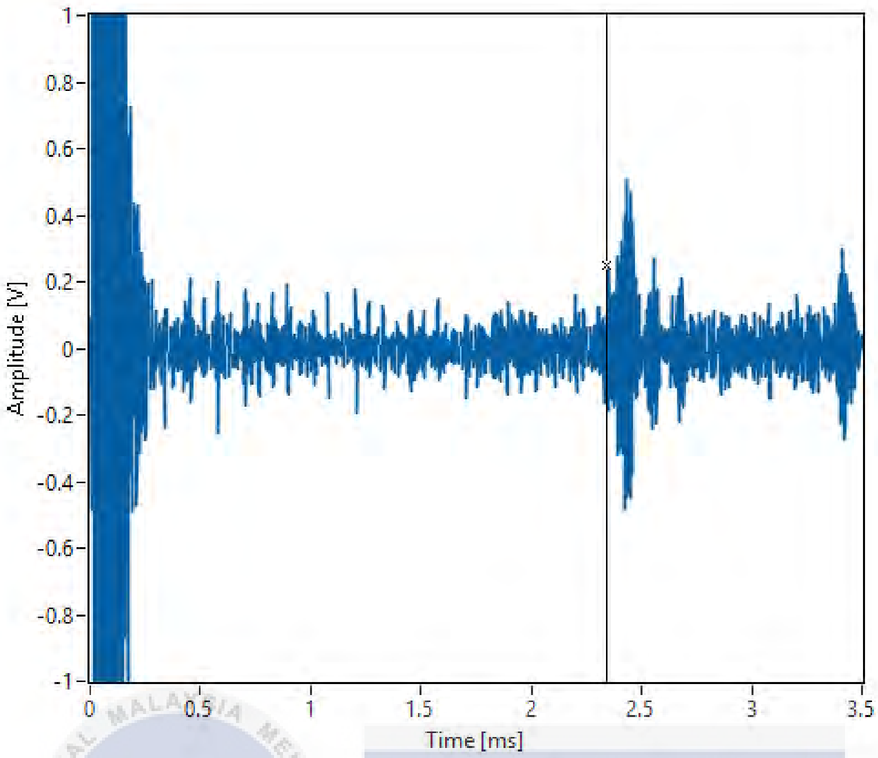


Figure 4.34: Waveform enhance at 150 kHz after L (0, 1) mode cancellation

The graphs below show the information from the enhanced waveforms above of aluminum pipe with an oblique defect, after L (0, 1) mode cancellation.

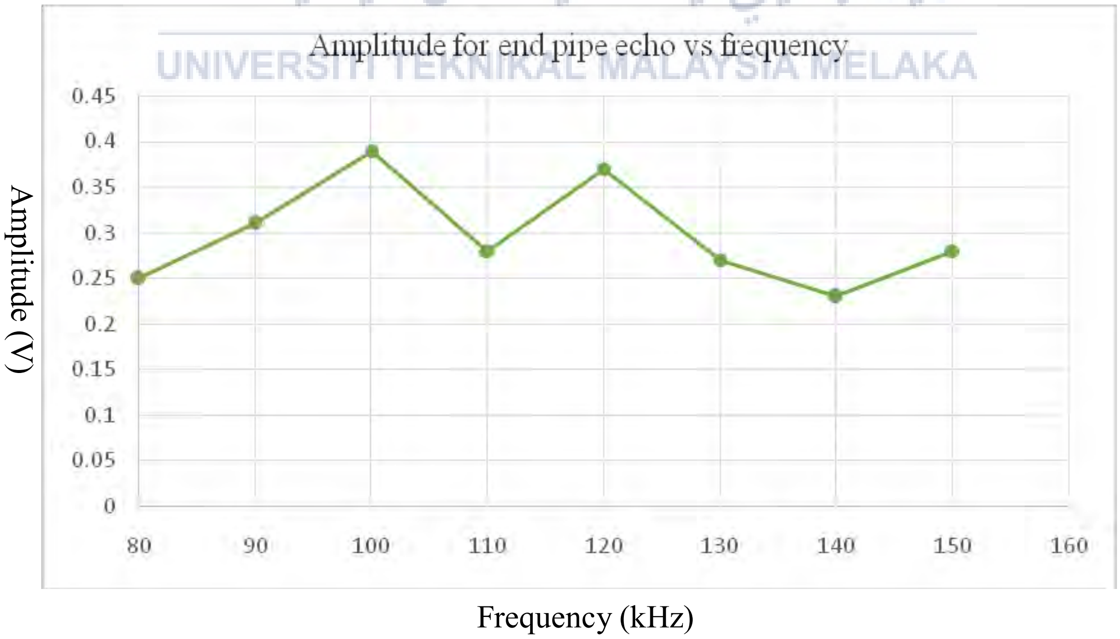


Figure 4.35: Effect of frequency excitation on amplitude of echo from the pipe end

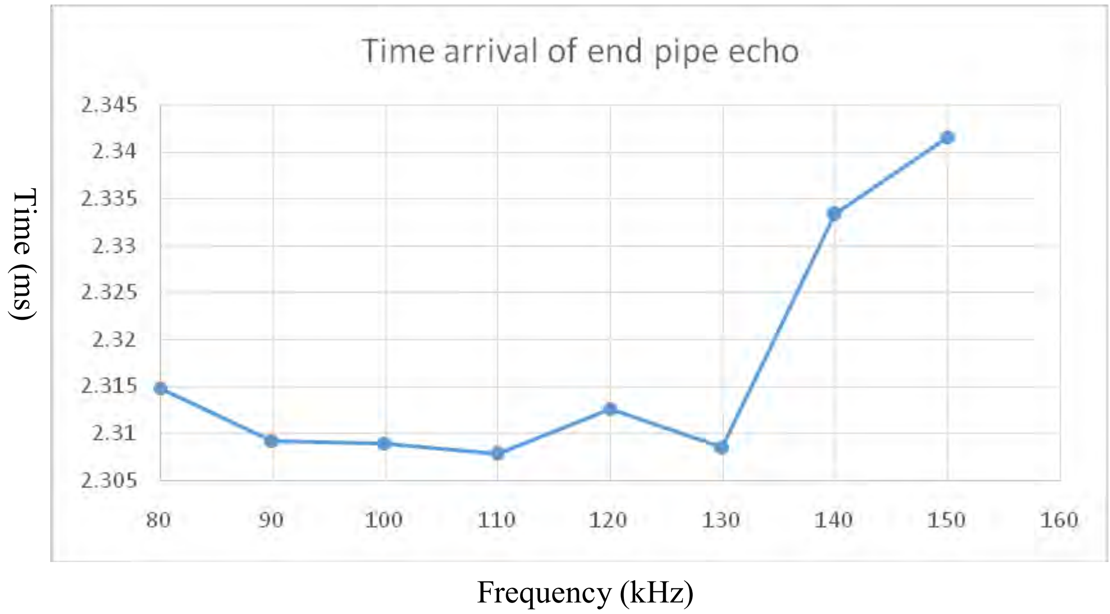


Figure 4.36: Effect of frequency excitation on time arrival of echo from the pipe end

Based on the above waveform graphs it is seem to the defect echo difficult to identify and this is because the low of sensitivity by using two angle beam transducer. In the other side, we can identify the end of pipe echo easily. From the Figure 4.33 above that shows the value of amplitude of the end of pipe echo with the different frequencies, the higher amplitude value within 100 kHz and the lower value lie in 140 kHz. Whereas, the Figure 4.34 illustrate the time arrival to end of pipe echo with different frequencies, in the frequency 110 kHz is the shortest period of time arrival to the end of pipe echo and the frequency 150 kHz take the longest period of time arrival to the end of pipe echo.

4.3Mode Identification

Below are the sample calculation of experiment to determine the distance of the wave propagated and time taken.

$$velocity, v = \frac{distance, d}{time\ taken, t}$$

From dispersion curve shown in Figure 3.24, the guided wave is propagate at frequency 100 kHz through aluminium pipe, and from the graph of the dispersion curve L (0, 2) when the frequency is set at 100 kHz, the group velocity from the graph of the dispersion curve is 5380 m/s. From the enhanced data of the perpendicular defect the group velocity calculated from the time travel to end of pipe defect after enhanced for different frequencies, 80 kHz, 90 kHz, 100 kHz, 110 kHz, 120 kHz, 130 kHz, 140 kHz and 150 kHz. Whereas the overall distance of the pipe is, L 600mm, so the group velocities calculated for each frequency as following.

80 kHz $$v = \frac{2L}{t} = \frac{2\times6}{0.002312057} = 5190.18\ ms$$

90 kHz $$v = \frac{2L}{t} = \frac{2\times6}{0.002304965} = 5206.153\ ms$$

100 kHz $$v = \frac{2L}{t} = \frac{2\times6}{0.002303856} = 5208.659\ ms$$

110 kHz $$v = \frac{2L}{t} = \frac{2\times6}{0.002305741} = 5204.4\ ms$$

120 kHz $$v = \frac{2L}{t} = \frac{2\times6}{0.002305674} = 5204.55\ ms$$

130 kHz $$v = \frac{2L}{t} = \frac{2\times6}{0.002318203} = 5176.423\ ms$$

140 kHz $$v = \frac{2L}{t} = \frac{2\times6}{0.002319149} = 5174.312\ ms$$

150 kHz $$v = \frac{2L}{t} = \frac{2\times6}{0.002305741} = 5159.586\ ms$$

From the above calculation, we can see obviously small difference in the values of group velocities calculated from the experiment result in pipe with perpendicular defect and the value of group velocity that obtained theoretical from the dispersion curve. This difference due to human error in observe the group velocity from the dispersion curve. So the difference is not much between the group velocities from experiment waveform in different frequencies and the group velocity from the dispersion curve the values still in the range of L (0, 2) mode, so they can be used to detect the location of defect in aluminum pipe.

4.4 Defect Location

For the case of 3 mm defect depth, the result obtained for aluminum pipe with perpendicular defect and oblique defect, also from the results above in the pipe with oblique defect we could not identify defect echo in waveform. However, in the pipe with perpendicular we can easily identify the defect echo and observe the arrival time to defect echo, where the group velocity calculated for each frequency that used in this experiment. The defect location can be identified based on the time arrival for defect echo and the group velocity for each frequency, so by using the equation (3.3) below the defect location for each frequency as following.

$$\text{Location of defect} = \frac{t}{2} x V_g$$

80 kHz $$L = \frac{t}{2} v = \frac{0.002}{2} \times 5190.18 = 5.19\, m$$

90 kHz $$L = \frac{t}{2} v = \frac{0.001992908}{2} \times 5206.153 = 5.18 m$$

100 kHz $$L = \frac{t}{2} v = \frac{0.001985816}{2} \times 5208.659 = 5.17\, m$$

110 kHz $$L = \frac{t}{2} v = \frac{0.001971631}{2} \times 5204.4 = 5.13\, m$$

120 kHz $$L = \frac{t}{2} v = \frac{0.001996217}{2} \times 5204.55 = 5.19\, m$$

130 kHz $$L = \frac{t}{2} v = \frac{0.001996643}{2} \times 5176.423 = 5.16\, m$$

140 kHz $$L = \frac{t}{2} v = \frac{0.001996099}{2} \times 5174.312 = 5.16 m$$

150 kHz $$L = \frac{t}{2} v = \frac{0.001994586}{2} \times 5159.586 = 5.14\, m$$

As the artificial defect made with 5m distance from the transducer position. The defect location is acceptable in all the frequencies as well which is approximately 5 m from transducer attached, from the values of the defect location we can say that in frequency 110 kHz we got the best value which is 5.13 m the closest to the artificial defect distance .

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1Conclusion

Guided waves are used for inspection in long pipes allow a defect screening from a fixed inspection location in insulated or underground pipes. Guided wave excitation can be performed by using angle beam transducer as used in this experiment. Inspection on artificial defects had been conducted using perpendicular and oblique defects that placed at the similar location from the transducers in pipes. Excitation of predominant L(0,2) mode from the two transducers successfully located the perpendicular defect at very closed resolution to its exact location in pipe. The defect echo is consistently appeared from the excitation of the burst signal with different frequencies from 80 kHz to 150 kHz. The use of five points in signal processing that reduce the component of L (0, 1) show higher of amplitude value for the defect echoes and reflection at the end of pipe. The defect echo and the end of pipe echo observed easily for pipe with perpendicular defect and the defect location is identified in all the frequencies, the 110 kHz has the nearest value to the position of the defect location on the pipe. However, there are no defect echo observed from oblique defect at the similar arrival time of defect echo obtained in pipe with perpendicular defect although after the signal enhancement. This indicates that the reflected wave from perpendicular and oblique defects are propagating in different behaviors in pipes. Therefore, it is difficult to observe the defect echo from oblique defect using the same transducers used in pipe with perpendicular defect.

5. 2 Recommendation

In order to get success in observing the defect echo in pipe with an oblique defect we recommend that:

- Increase the number of angle beam transducers in order to increase the sensitivity to observe the oblique defect.
- Change the position of the angle beam transducers.

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APPENDIX

No.	Activities	2016				2017					
		Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
1	Research background study										
2	Literature review										
3	Research review										
4	Material purchase										
5	Perpendicular defect fabrication										
6	Transducer casing and wedge design										
7	Transducer casing fabricating										
8	Wedge and holders design and fabrication										
9	Oblique defect fabrication and experiment setup										
10	Defect inspection										
11	Data analysis										
12	Report writing and submission										