FEATURES EXTRACTION OF GEOMETRY DEFECT MONITORING IN CYLINDRICAL PIPING

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ABSTRACT

This study aims to investigate the features of wave in the single Polyvinyl Chloride (PVC) cylindrical pipeline. This project involved the monitoring process of without defect and defect single pipeline. The experiment process involved the simple geometry defect including the horizontal and vertical cracks. The sensor used in this project is the Piezoelectric Wafer Active Sensor (PWAS) which the sensors use to detect the lamb wave. As a part of non-destructive test process, this crack detection process involving the process of analyzing wave obtained from the sensor. The size of defect is the manipulated variables use in this project which including the size of crack start from 1 cm to 5 cm. However, this project is only concentrate only on the semicircular part of the cross-section of the pipeline. Because of that, all the six sensors used in this project attached only in the distance 36º between each sensor. This project indicates the different pattern of wave for each sensor as each sensor has own angle from the midpoint of the circular cross-section. The different pattern produced by each sensor in the present of crack and for normal pipe was analyzed for the understanding the effect of the defect in the normal single PVC pipeline. The data produced by each sensor then was filter to get the best accurate and consistent data. Filter data next to analyzed followed by the features choice for time domain including the maximum peak, minimum peak, velocity of the wave and maximum amplitude versus angle of the sensors for both horizontal and vertical defect. The results of each features is discussed graphically in results and discussion chapter.

ABSTRAK

Projek ini bertujuan untuk menyiasat sifat gelombang pada paip tunggal Polyvinyl Chloride (PVC). Projek ini melibatkan proses pemantauan untuk paip yang berkondisi tanpa kecacatan dan paip yang berkondisi kecacatan secara geometri. Kondisi kecacatan dalam projek ini cuma melibatkan kecacatan geometri secara menegak dan melintang. Didalam projek ini, sensor yang digunakan adalan Piezoelectric Wafer Active Sensor (PWAS) dimana sensor ini boleh bertindak mengesan lamb wave. Sebagai salah satu proses ujian non-destructive, proses mengesan kecacatan ini melibatkan analisis gelombang yang diperoleh dari sensor. Saiz kecacatan yang dikenakan bertindak sebagai pemboleh ubah manipulasi dimana saiz yang digunakan adalah 1cm sehingga 5 cm. Walaubagaimanapun, projek ini Cuma melibatkan separuh bulatan daripada keratan rentas bulatan paiptersebut. Oleh kerana itu semua enam sensor yang digunakan akan mempunyai jarak 36º sudut diantara satu sama lain. Jadi, analisis yang akan diperoleh akan melibatkan bentuk gelombang yang berbeza yang dihasilkan oleh setiap sensor. Selain daripada itu, projek ini juga akan digunakan untuk membezakan kesan bentuk gelombang yang terhasil daripada kecacatan geometri yang dikenakan keatas paip PVC tersebut. Maklumat yang terhasil daripada sensor tersebut akan menjalani proses penapisan untuk mendapatkan data yang lebih tepat dan konsisten. Data yang ditapis kemudiannya akan dianalisis mengikut sifat yang boleh digunakan dalam domain masa melibatkan puncak gelombang tertinggi, puncak gelombang terendah, kelajuan gelombang dan kesan amplitud tertinggi keatas sudut sensor untuk kecacatan menegak dan melintang. Keputusan daripada analisis sifat-sifat ini akan dibincangkan melalui gambaran graph didalam bab keputusan dan perbincangan.

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LIST OF SYMBOLS AND ABREVIATIONS

$\delta(n)$	-	Filter Function
∇^2	-	Space Variable
Λ	-	First Lame Parameter
ρ	-	Density
μ	-	Shear Modulus
A	-	Area of Pipe
A	-	Amplitude of the Sine Wave
C	-	Fixed Constant
D	-	Diameter of Pipe
E	-	Weld Joint Efficiency
f	-	Source Function (Driving Force)
$\lvert f(t)\rvert$	-	Absolute Value of Magnitude
$\lvert f(t)\rvert^2$	-	Energy Density per Unit Time at Moment T
$f^{`}(n)$	-	Filtered Signal
F	-	Frequency of the Sine Wave
K	-	Bulk Modulus
P	-	Internal Design Pressure of Pipe
Q	-	Flow Rate
Ro	-	Outside Radius of Pipe
S (T)	-	Signal As A Function of Time
t	-	Nominal Wall Thickness of Pipe

T_2	-	Ending Time Moments for Signal Acquisition
T_1	-	Starting Time Moments for Signal Acquisition
$\mathbf{u}$	-	Displacement Vector
V	-	Velocity of Flow
ADC	-	Analog to Digital Conversion
CA	-	Corrosion Allowance
DAC	-	Digital to Analogue Conversion
RMS	-	Root Mean Square

CHAPTER 1

INTRODUCTION

1.1 Project Background

The piping system is the one of mechanical equipment needs to complete some of the daily operation. As human needs water as the general sources for a life, the piping system concomitant as major system to convey water from the water center processes to the all place required. There are not until there as the industrial plant such as oil and plant which use piping as a major tool to run the business successfully.

In any Plant, whether House Plant, Industrial Plant, Nuclear Plant, Gas Plant (On-shore or Off-shore) needs the piping system. The piping system role as the medium used to convey the fluid including the water, sewage and slurry but arguably the most valuable are those transporting fuels, oil, natural gas and biodiesels that have the various level of temperature.

Instead of the various used of the piping system especially for human needs, there are many things to consider in order to setup all pipeline equipment in the building. The force, load and environment that acting on the pipeline must be adequate to ensure the system in the best performance to do a job. Because of all the effects are not constraint, there is still having some problems that acting on the pipeline itself.

The good planning of the piping system was requested to guarantee the smooth of the process flow and in the same time the systems reach the life expectancy suitable with the planning cycle. However, there are still found the fail of pipeline system either when installation or operation. This problem clearly wasted because of the system needs to stop from the operation for a repairing.

Because of this situation, the time taken is required to make the system back to the normal operation. The responsible person such as engineers and technician play the main role for this problem to ensure the system can be in the track as soon as possible. To solve this problem, there are some steps to follow. One of the important step require in this piping maintenance process is the detection of the problem.

Because of that, the responsible person needs concentrate more in this detection step which is analyzing the various types of piping problem. In the present, this piping crack was detect using non-destructive test which include various types of techniques such as Radiography, Ultrasonic, Eddy Current, Fluorescent and Dye Penetrate and Magnetic Particles (Silowash, 2010).

Nondestructive testing is not preferred only for crack detection but also benefited to analyze the porosity, wall thinning from corrosion and many sorts of disbonds. In other function NDT is also used for material properties including material identification and microstructure characteristics (Lynn & Fuerst, 1998).

1.2 Problem Statements

Piping system is one of the engineering field used familarly in human life nowadays. Most everythings in human activities involving the pipe as medium to convey the fluids (gas or liquid). As evolution of industry, such as oil and gas, automobil, aeronatic, chemical and others, pipe become one of the main equipments used in order to transfer fluids from one part to another part. The environment of technology change made the improvements of the piping system itself.

In order the common used of the piping system, the problems involving the pipe easily happened. By refer to the previous time, the piping problem solve using the manual method which the damage or broken pipe detected and replaced manually.

Recently, non-destructive test use and become major method for piping crack detection but it still needs too many improvement for a steps besides higher technical knowledge . This indirectly make the cost higher and long time duration.

The failure of piping system normally happened causes by corrosions and leakages. There are three types of corrosion generally in piping system. According to the corrosion index assesses three general types :atmospheric corrosion, internal corrosion, and subsurface corrosion (Muhlbauer, 2004). The behaviour of environment can cause the failure of the piping system. This failure normally started with small leakage. For the normal cold water pipeline, the leakage problem is the common problem. As the results, leakage cause the waste of clean water.

Because of this problem, the easy method require to reduce cost and in the same time to make the steps more easily so that it no need higher technique to do the steps. The Signal Processing (SP) is one of the new method applied in engineering. This method was used in many field of engineering nowadays.

In this project, the piping defect will be identify and monitor using the wave that appears directly on the screen of receiver. All characters of the wave that appear in the screen will be analize followed by the types of the piping crack and the characteristics. The charactheristics of the wave is refer to the features use of the wave in analysis of time domain.

1.3 Objectives

The Signal Processing nowadays intensified as the new knowledge applies in the engineering. The main objective of this research is to obtain damage characteristics of a cracked related issue in a single pipeline structure. In order to achieve this main objective, several issues/ criteria are taken into consideration as follows:

1. To prepare sensors network equipment for cracks detection in a single pipeline.
2. To obtain damage features from the signal received.
3. To compare the damage characteristics between a normal and damaged pipe.

1.4 Project Scope

To achieve the objective stated in the mission statements, the boundary is setup for the element involving in the project:

1.4.1 Pipe

a) The sample used is the single circumferential hollow pipeline with homogenous shape and without any connection
b) The pipelines in this project is only concentrate on Polyvinyl Chloride (PVC)
c) This project will cover the normal leakage problem in the pipeline.(Horizontal & Vertical Cracks)

1.4.2 Signal Processing

a) This project applies the Lamb Wave as the wave transfer from the transducer to receiver.
b) Piezoelectric active wafer sensor (PZT) role as the sensors used in this project.
c) Software for analysis for this project is MATLAB 7.11.0 (R2010b)

1.5 Project Justification

The application of advance signal processing in pipeline system for this project recently still in the beginning stage as the technique was newly introduced in other engineering field. The technique shows other solution can be develop in order to solve the surface crack problem especially in piping system. The solution of piping crack problem carried out by NDT techniques to solve nowadays is not fixing.

As piping engineering knowledge expands wider in the new technique, the “traditional” problems currently solve start from the design, analysis or construction.

With the other external issues such as environment, material used and others, the problem occurred but in the small accuracy. In this matter, the technique develop must be modified to be compatible with the problem. The properties of the technique including sensitivity, accuracy and consistency required to achieve the target.

Cost, time and safety are the main aspect to consider for developing the new technique. These three aspects is the main influence to construct new technique in order to satisfy on the side of engineering and business while the recent technique Non-Destructive Test act as comparator. It’s sure, the system maybe can’t satisfy all the aspects but it’s probably help towards the aim for the future recommendation.

As in depth of this project, the comparison of wave acceleration for the frequency domain analysis is very useful. This is because to get any related data through the process to find the real measurement of wave acceleration, the other information such as velocity and displacement of wave can be generate. That means the comparisons not only fix on the data of wave acceleration but for other information needed.

The choice of the material for pipe including the PVC shows the importance of those materials in piping system. All of this material plays important role in the construction of piping system for water transfer. This project will show how the advance signal processing able to slot with this type of material in the same time for the application of wave transfer in the homogenous hollow cylindrical.

CHAPTER 2

LITERATURE REVIEW

2.1 Signal Processing

Signal Processing may be defined as the manipulation or modification of a signal for a certain purpose. In general, signal processing was done using analog components like resistors, capacitors, inductors and operational amplifiers (Philips, 1998).

A signal can be described as any physical quantity that varies with time, space or other domains and it contains information that we need to analyze. The entities appears from the signals will be through the analyzing step to identified the information needed (Parasuram, 2001).

Everyday we receive uncountable number of signals and we send as many. The signals can come in many different forms. We will receive all the signals mostly through our sense and converted the signals to information through our brain. In a similar form for an electrical system would convert the signals into electrical form using transducers.

In general, signals are often thought of as a pattern of variations in time. This pattern of variations can sometimes be modeled as a mathematical function. For example, if the amplitude of the signal, *s*, and moves up and down periodically according to a sine wave pattern, we may represent this signal in the form of $s(t) = Asin(2\pi ft)$.

The expression, *s (t)* denotes the signal as a function of time, t. *A* and *f* are the amplitude and frequency of the sine wave respectively. For different values of *t*, the values of *s* may be computed by substituting the values of *t* into the right hand side of the equation.

Signals may be classified as continuous-time signals and discrete-time signals in the way they vary with time. A continuous-time signal is one that has values or information at every instance in time (Chow & Ercan , 2007).

2.2 Time Domain Analysis

Signals are the physical variables that change with time. It normally described by plotting them on two-dimensional graphs as graphical view. It also can be shown in the mathematical expression to get more precise result. The use of mathematical model ensures the complete representing the processing of these signals.

In the time domain analysis, there are three types of the common operation that use in order to analyze the data. The convolution, deconvolution and correlation are the familiar operation use in the time domain analysis.

Convolution described about shift Invariance, homogeneity and additivity are very useful created of change in impulse to impulse response. What is important in the steps is the way to measure the system response to the unit impulse. The function measure simply can be identified following the function measurement (Heeger, 2000).

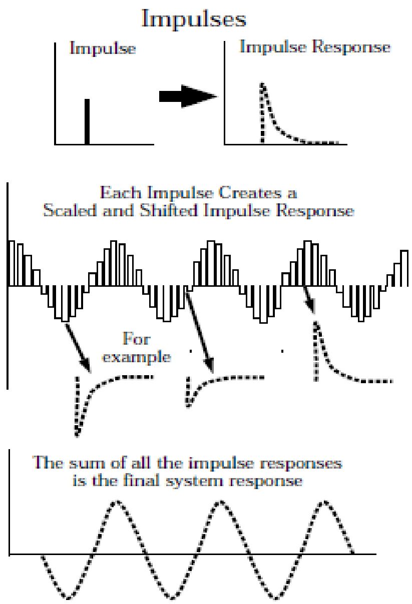


Figure 2.1: Characterizing a Linear System Using Its Impulse Response (Heeger, 2000)

By using the sifting property of the impulse signal, we can write

$$\int_{t_1}^{t_2} x(\tau)\delta(\tau)dt = x(0)\ for\ t_1 < 0 < t_2 \tag{2.1}$$

It is possible to determine an unknown input signals, x(n), if the impulse response of the system, h(n), and the output signal, y(n), are known. Deconvolution use as the reverse operation of convolution for the solution. In most cases, the attention is in the values of a sequence at positive time axis; hence the generalized convolution equation can be simplified to obtain:

$$y(n) = \sum_{k=0}^{n} h(k)x(n-k) \tag{2.2}$$

Correlation, similar to convolution, is mathematical operation that is used to measure degree of similarity between two signals. It is often using to detect a known waveform in noisy background, or to detect periodicity or to measure delays. The mathematical correlation can be shown as:

$$r_{12} = x1 \otimes x2 = \sum_{n=-\infty}^{\infty} x1(n)x2(n) \tag{2.3}$$

The characteristics contained in time-series lamb wave signal, $f(t)$, that may be beneficial to damage identification include:

i. The absolute value of magnitude ($|f(t)|$)
ii. The root mean square (RMS) of the signal ($\sqrt{\frac{1}{T_2-T_1}\int_{T_1}^{T_2} f^2(t)dt}$ where T_2 and T_1 are the ending and the starting time moments for signal acquisition.
iii. Standard Deviation
iv. Kurtosis
v. Characteristic Time Moment
vi. Trend
vii. Cyclical Component
viii. Time-of-Flight (ToF)

Because of the propagation of lamb waves is continuous transportation of energy in kinetic and potential forms, a time-series lamb wave signal $f(t)$ is often examined in accordance with its energy distribuition in the time domain, defined as;

$$E = \int_{t \geq 0} |f(t)|^2 dt \tag{2.4}$$

Where $|f(t)|^2$ is the energy density per unit time at moment t.

Digital Signal Processing in the time domain is typified by;

i. Hilbert Transform
ii. Correlation
iii. Time Reversal
iv. Exponential Smoothing
v. Regression (curve-fitting)
vi. Extrapolation

vii. Differencing
viii. Decomposition

2.3 Digital Signal Filter

A lamb wave signal usually contains a variety of components in a wide frequency range of which only certain bands are of interest for damage identification, such as bands whose central frequency is the same as that of activation. A digital filter is a linear transfer function, to convolve and weight a descritised lamb wave signal, f(n), (n = 1, 2, …, N), described by N sampling point,

$$f^{`}(n) = \delta(n) * f(n) \tag{2.5}$$

Where $f^{`}(n)$is the filtered signal and $\delta(n)$is the filter function

The counterpart of equation in the frequency domain is

$$F^{`}(\omega) = \Delta(\omega).F(\omega) = \frac{b_1 + b_2 e^{-i\omega\,(1)} + b_3 e^{-i\omega\,(2)} + \cdots + b_n e^{-i\omega\,(n-1)}}{a_1 + a_2 e^{-i\omega\,(1)} + a e^{-i\omega\,(2)} + \cdots + b_m z^{-i\omega\,(m-1)}} \tag{2.6}$$

By setting the filter coefficients, as different values in equation, a digital filter for a lamb wave signal can be one of following, in terms of filtering effect:

i. Low-Pass filter
ii. High-Pass filter
iii. Bandpass filter
iv. Bandstop filter

The used of Ft and FFT to transfer wave from time to frequency domain can cause loss of temporal information of signal such as magnitude of signal amplitude and ToF (Edwards, 2006).

2.4 Analog Signal to Digital Signal

Most of the signal directly encountered in science and engineering are continuous. Analog to digital conversion ADC and digital to analogue conversion (DAC) are the process that allows digital computers to interact with these everyday signals (Smith, 2003).

Digital information is different from its continuous counterpart in two important respects which is sampled and quantized. Both of these restrict how much information a digital signal can contain.

The hearts of computers-based data is the analog to digital converter (ADC). Its input is voltage while the output is a digital numbers proportional to the input voltage. In general the digital output of the ADC is related to the input voltage by the algorithm (e.g for 8-bit digital number):

$$Digital\ output = Integer\ part\ of\left[2^8 \times \left(\frac{volts\ input}{10}\right)\right] \qquad (2.7)$$

Most of ADC`s use a circuit called a comparator. The circuit contains two inputs and one output. The inputs are analog signals and the output is a single bit digital signal. If the voltage applied to the signal input is greater than the voltage applied to the reference than the output is 1.

There are several types of ADC converters use nowadays. The simplest type of ADC is the counter type ADC. The input signal of ADC connected to the signal input of comparator. The system of this converter looks simple but as the number of ADC bits increases the time taken to scan through all of the possible values lower than input will grow quickly.

Next is the Successive approximation type ADC is to start with initial reference voltage at half the maximum voltage range of ADC. This determines which half of the ADC`s range includes the input voltage and thus the first bit of the output number in binary. For the next steps is the repeated every results of a half in half as number of bits associated with the ADC.

The flash type ADC is a 2-bit ADC and the fastest ADC in which there are as many comparators as there are possible outputs. Rather than changing the voltage to one comparator, in a flash type ADC each voltage that on might apply to the single comparator in a counter type is hard wired to its own comparator. A bunch of logic circuits determine which is the largest reference signal less than the input signal. The measurements are done in one step but these get expensive quickly with increases resolution.

Other type of ADC is Wilkinson type ADC use to measure the input voltage, by using it to charge a capacitor. The capacitor is then discharged at a constant current. The discharge time is measured and its show a time is proportional to the input voltage. For 2-bit Wilkinson ADC, it takes 4 clock ticks for this capacitor to discharge if it is initially at the maximum voltage for the ADC.

2.5 Piping System and Pipeline

Pipe is tubular section or hollow cylinder, usually but not necessarily of circular cross-section, used mainly to convey substances which can flow liquids and gases, slurries, powders, masses, or small solids. It also can be used for structural applications which hollow pipe is far stiffer per unit weight than solid members.

Pipe or reasonable facsimiles to modern pipe began to appear as people started to live in towns **(**Ling, 2008**)**. That move created the need to transfer water from the source, usually a stream or spring, to some central place in the town. From the central place, it expands to the side area as the increasing of the total people inside the town.

Through the modern town as the concentrated place for many people nowadays, the systematic pipeline was introduced. When the pipeline is built, the construction project not only covers the civil works to lay the pipeline and built the pump/compressor station; it also needs to cover all the works related to the installation of the field devices that will support the remote operation (Escoe, 2006).

2.5.1 Piping Theoretical

Diameter of pipe = d, in

Area of pipe, $A = \frac{\pi d^2}{4}$, in2

Velocity of flow = V, ft/sec

Flow rate, Q, ft^3/s = Area x Flow Velocity

Density and Mass Flow Rate

Mass = Volume x Density

Flow rate, Q = $\frac{Mass\ (\frac{lb}{sec})}{Density\ \ (\frac{lb}{ft^3})}$

Pressure

Pressure = Force / Area

General Hoop Stress formula

$$\sigma_H = \frac{P[R_o - 0.4(t - CA)}{Et} \qquad (2.8)$$

Where,

CA = corrosion allowance, in. (mm)

Ro = Outside radius of pipe

P = internal design pressure of pipe, psi (Mpa)

t = nominal wall thickness of pipe, in. (mm)

E = weld joint efficiency

2.5.2 Piping Codes

i. ASME

Each of the codes refers to a piping system. While the specific definition of a piping system may vary from the codebook to codebook, this simplified book treats a piping system according to the following definition.

B31.7 1969 edition define the piping system as a set of components including pipe, flanges, pipe fitting, bolting, gaskets, relief devices and the pressure retaining parts included in any stress analysis. It also includes the hangers, supports and other equipment necessary to prevent overstressing of the pressure-retaining parts but not include the structure and equipments and foundations, except as they may affect the stress analysis (Ellenberger).

It captures the gist of the many separate definitions each book might offer as well as the reasons of the codes. That reasons is to define the design and fabrication of a system that offers a reasonable expectation of being safe when operated as intended. Table 2.1 and 2.2 shows pipe codes for aboveground and buried pipe.

ii. Aboveground Codes and Buried Codes

Table 2.1: Aboveground Codes

Codes	Division
B31.1	Power Piping
B31.3	Process Piping
B31.5	Refrigeration Piping and Heat Transfer Components
B31.9	Building Service Piping

Table 2.2: Buried Codes

Codes	Division
B31.4	Liquid Transportation System Pipeline Code
B31.8	Gas Transmission and Distribution Pipeline Code
B31.11	Slurry Transportation Piping System

2.6 Damage Mechanism

A proactive approach is the best defense against failure by damage mechanisms. Note that API 579 does not describe how to find corrosion, but what to do when you find it (Muhlbauer, 2004). Damage mechanisms can be categorized into two prime categories- preservice flaws and in-service flaws. Preservice flaws are caused by following:

i. Materials flaws caused by production
ii. Welding-induced flaws
iii. Fabrication fit-up
iv. Heat treatment flaws resulting in embrittlement

In-service flaws are caused by the following:

i. General Corrosion
ii. Localized Corrosion
iii. Galvanic Corrosion
iv. Environmental Cracking
v. Erosion-corrosion, Cavitation, and Fretting
vi. Intergranular Corrosion
vii. Dealloying
viii. High-temperature Corrosion or Scaling
ix. Internal Attack
x. Carburization
xi. Hydrogen Attack

2.7 Piping Crack Detection

2.7.1. Detection Theory

The development of detection theory can be divided into 2 parts (Jaffe, 2000). It's included the first part detection and another part is the estimation. In detection, we only interested in the determination of whether specific signal is present among the other interfering signals. Estimation used to determine or estimate the characteristics of desired signals. To develop estimation theory, we need to refer or shared many of analytical aspects of detection problem.

2.7.2. Wave Movement

i. Amplitude

The strength or volume of a signal usually measured in decibels.

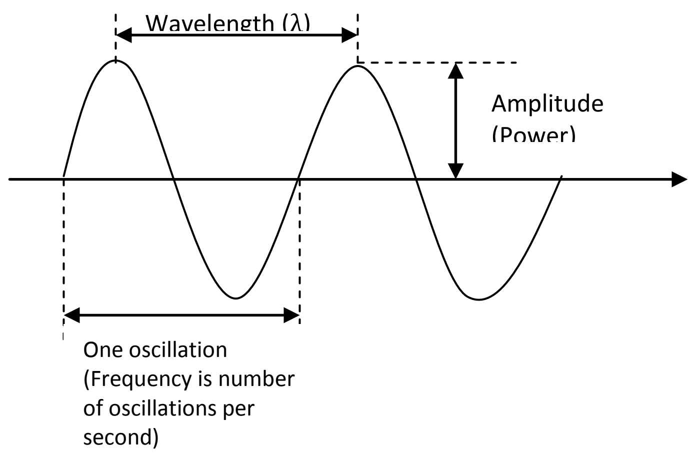


Figure 2.2: Amplitude in Wave

Amplitude is the power of a signal. The amplitude also can define as the magnitude of changes in variables that oscillate with the oscillations of each oscillation of the system period. The greater amplitude will cause the greater energy carried. Figure 2.2 show the example of amplitude in wave.

In physics, maximum displacement amplitude is from zero of other value of the other positions. Amplitude is important in the description of phenomena such as light or sound waves. In general, the greater amplitude of the wave, the more energy is required, such as bright light or sound louder.

The amplitude of wave is the maximum displacement or the maximum value. It enables to achieve the mean position during a cycle. Are both is positive and negative. The larger amplitude of the sound will cause of the sound wave produced stronger.

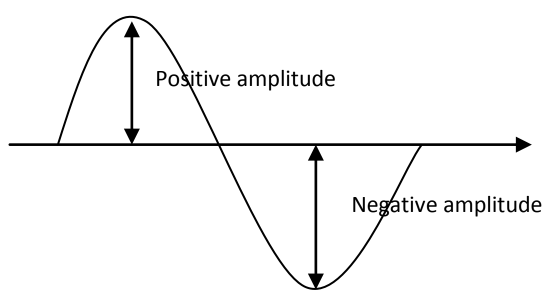


Figure 2.3: Positive and Negative Amplitude

ii. Wave Equation

Waves produced when something vibrant periodically source and touch other particles. A moving wave pattern begins to develop when the wave are produced (Carcione *et al*, 1998). Frequency for each individual particular vibrates is same with frequency at which source vibrates. Period of vibration for each individual particle in the medium mode is same as the vibration source. Complete movement form one wave cycle is start when a source replace particle first than the rest and return back to other, next below from another and finally return to rest.

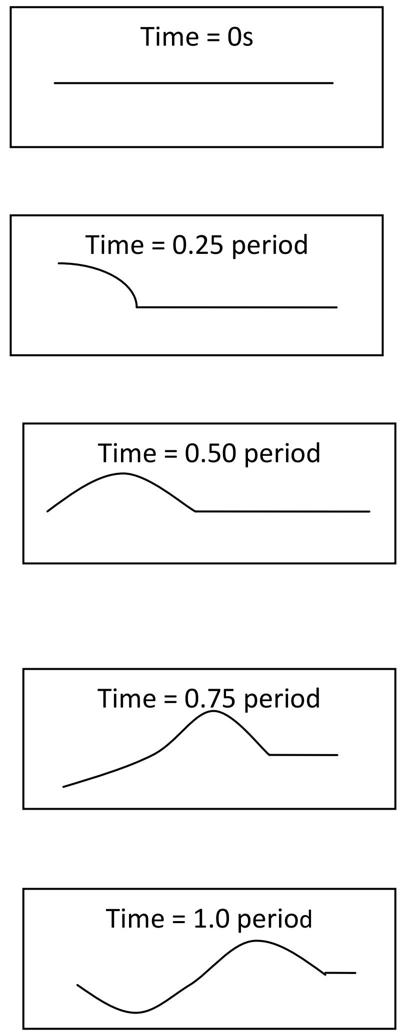


Figure 2.4: Complete Wave Cycle

Figure 2.4 shows several snapshots of the production of a wave. In a period of time, the wave observed during the same amount of time, the leading edge of the disturbance has moved a distance of one wavelength. All of this information will combine with the equation for speed equal to distance or time. It also can be said that the speed of a wave is wavelength or period.

$$\text{Speed} = \frac{\text{Wavelength}}{\text{Period}} \tag{2.9}$$

or

$$\text{Speed = Wavelength x Frequency} \tag{2.10}$$

There are many variations in wave equations. Hyperbolic partial differential equations are example of wave equation. The wave equations concerns a time variable *t*, one or more space variables x_1, x_2 ..., x_n and a scalar function is $u = u\ (x_1, x_2..., x_n \bullet t)$, whose values could model the height of a wave. The equation for *u* is:-

$$\frac{\partial^2}{\partial t^2} = c^2 \nabla^2 u \tag{2.11}$$

Where $\nabla^2$is the space variable and c is a fixed constant.

Solution of this equation is initially zero and expanded at the same speed throughout the area from all directions, like a physical wave motion. The constant c is identified with the propagation speed of the wave. This equation is linear and in physics this property called as superposition principle. For model dispersive wave phenomena, those in which the speed of wave propagation varies with the frequency of the wave. The constant c is replaced by the phase velocity.

$$V_P = \frac{w}{\kappa \bullet} \tag{2.12}$$

Phenomena in the speed depend on the amplitude of the wave are modeled by nonlinear wave equations:

$$\frac{\partial^2 u}{\partial t^2} = c\ (u)^2 \nabla^2 u \tag{2.13}$$

Waves can be emphasizes to the other movements, for example the sound propagation in a moving medium such as flow gas. In this case, the scalar u will contain a Mach factor which is positive for waves travelling along the flow and negative for the reflected wave.

Elastic wave equation in three dimensions describes wave propagation in homogeneous isotropic elastic medium (Aster, 2011). The materials most solid elastic, so this equation describes phenomena such as seismic waves in the earth and used ultrasonic waves to detect defects in the materials. Although linear, this equation has more complex from of the equations given above because it must take into account both the longitudinal and transverse movement.

$$\rho\ddot{\mathbf{u}} = \mathbf{f} + (\lambda + \mathbf{2}\mu)\nabla(\nabla \cdot \mathbf{u}) - \mu\nabla \times (\nabla \times \mathbf{u}) \qquad (2.14)$$

Where:

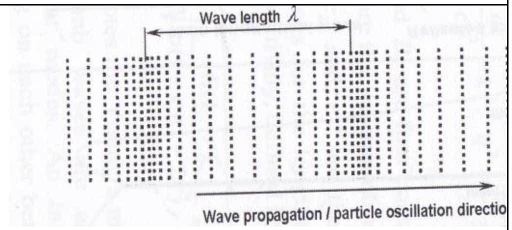
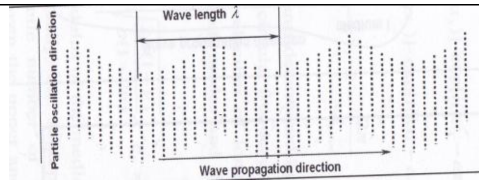
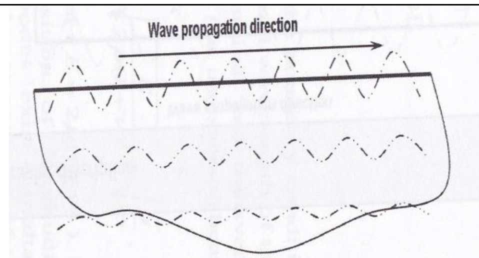
- λ and μ are the so-called Lame Parameters describing the elastics properties of the medium.
- ρ is the density
- $\mathbf{f}$ is the source function (driving force)
- $\mathbf{u}$ is the displacement vector.

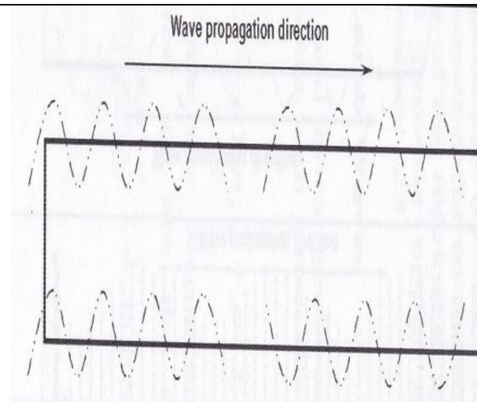
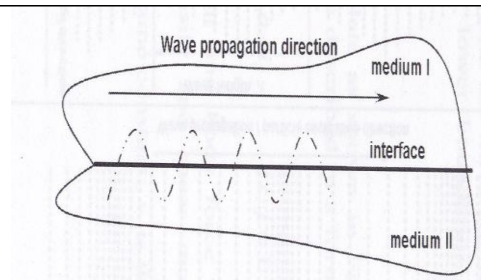
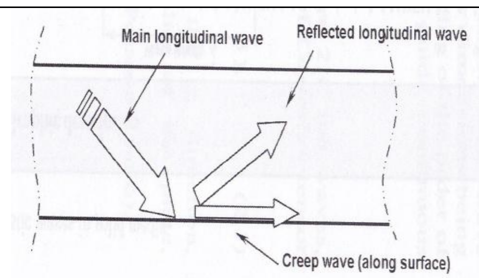
In this equation, both force and displacement are vector quantities. Thus, this equation is sometimes known as the vector wave equation.

iii. Elastic Wave in Solid Media

Elastic wave in solid medium can be one of the modalities describe in the Table 2.3 distinguished by the motion of particles. Amongst such wave modalities, lamb waves refer to those in thin plates that provide upper and lower boundaries to guide continuous propagation of the waves (Zhongqing & Lin, 2009).

Table 2.3: Elastic Wave in Solid Media

Wave type	Definition and Characteristic	Graphical Description
Longitudinal Wave	Travelling in the medium as a series of alternate compressions and rarefactions, a longitudinal wave vibrates particles back and forth in the direction of wave propagation.	
Shear Wave	Also termed a transverse wave, a shear wave is generated under vibration of particles perpendicular to the direction of wave propagation.	
Rayleigh Wave	Also defined as a surface wave, a Rayleigh wave exists along the free surface of a semi-infinite (or very thick) solid, decaying exponentially in displacement magnitude with distance from the surface	

Lamb Wave	Also known as a plate wave, a lamb wave exists in a thin plate-like medium, guided by the free upper and lower surfaces. Infinite wave modes are available in a finite body, and their propagation characteristics vary with entry angle, frequency and structural geometry.	
Stonely Wave	A Stonely wave is a kind of wave existing at the interface between two media or in the neighborhood of a free surface.	
Creep Wave	Also called a head wave, a creep wave is generated by refraction of a longitudinal wave from a boundary with the same propagation velocity. It has similar behavior to a longitudinal wave.	

iv. Lamb Wave

Lamb waves can be generated in a plate with free boundaries with an infinite number of modes for both symmetric and anti symmetric displacement within the layer (Jingjing, 2003). The symmetric mode is also called the longitudinal modes as the average displacement thicker over the plate or layer in the longitudinal direction. Anti symmetric mode is followed to display average displacement in the transverse direction and these modes also can call as bending mode.

Lamb waves propagate in solid plates. They are elastic wave particle motion in the plane containing the direction of wave propagation and normal to the plate. Their properties become quite complex. A medium is not limited to support modes of waves moving at the velocity of a unique. But the plate support only modes of an infinite set of lamb waves. The velocity depends on the relationship between the wavelength and the thickness of the plate.

Lamb's equations were derived by setting up formalism for a solid plate having infinite extend in the *x* and *y* directions, and thickness *d* in the *z* direction. Sinusoidal solutions to the wave equations were postulated, having x- and z- displacement of the form:

$$\xi = A_I f_I(z) e^{i(wt-kI)} \quad (2.15)$$

$$\varsigma = A_{\approx} f_{\approx}(z) e^{i(wt-kI)} \quad (2.16)$$

This form represents sinusoidal waves propagating in the *x* direction with wavelength 2π/k and frequency ω/2π. Displacement is a function of *x, z, t* only. There is no displacement in the *y* direction and no variation of any physical quantities in the *y* direction. The physical boundary condition for the free surfaces of the plate in that the component of stress in the *z* direction at *z=+/-d*2 is zero. Apply these two conditions to the above formalized solutions to wave equation. A pair of characteristics equations can be found. These are:

$$\frac{\tan(\beta d/2)}{\tan(\alpha d/2)} = -\frac{4\alpha\beta k^2}{(k^2-\beta^2)^2} \quad (3) \tag{2.17}$$

and

$$\frac{\tan(\beta d/2)}{\tan(\alpha d/2)} = -\frac{(k^2-\beta^2)^2}{4\alpha\beta k^2} \quad (4) \tag{2.18}$$

Where,

$$\alpha^2 = \frac{\omega^2}{c_I^2} - k^2 \quad \text{and} \quad \beta^2 = \frac{\omega^2}{c_t^2} - k^2 \cdot \tag{2.19}$$

Inherent in these equations is a relationship between the angular frequency ω and wave number k. Numerical methods are used to find the phase velocity $c_p = f\lambda = \omega/k$, and the group velocity $c_g = d\omega/dk$ as function of d/λ or *fd*. c_I and c_t are the longitudinal waves and shear wave velocities respectively (Soon *et al*, 2004).

v. Body Wave

S-wave is one of the two main types of elastic body waves. S-wave also called as an elastic S-Wave because S-wave move through the body object, unlike surface waves (Love Wave and Rayleigh Wave). S-Wave is a type of seismic waves. S-wave moves as a shear or transverse wave, so motion is perpendicular to the direction of wave propagation. S-wave like the wave in rope and not move through the Slinky waves, P-Waves. Waves travels through an elastic medium and restore the main force comes from shear effects. These waves are not branched and they will continuity equation for incompressible media:

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