A STUDY OF PIPE LEAK SOURCE LOCATION USING SINGLE CHANNEL ACOUSTIC EMISSIONS (AE) TECHNIQUE

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ABSTRACT

This project was carried out as a study of pipe leak source location using single channel acoustic emissions (AE) technique. The objectives of this project are to study a reliable and affordable system capable of monitoring pipe leak and also to locate the source of the pipe leak using AE technique. A test rig consists of the pipe without leak and the pipe with leak was developed using circumferential of a galvanized steel pipe to run the experiments. The fluid used was water throughout the experiments. The flow of the water was controlled by a ball valve. The source of the AE signals was from the leak and it was captured using AE sensor with the help of Acoustic Emission Detector 2.1.3 software. For all pipe conditions, the values of hits, counts and RMS (average, maximum and minimum) were recorded and analyzed. All the values recorded were compared between the pipe without leak and the pipe with leak (full open valve and full close valve). The results were gained from 8 marked points each for all pipe conditions. The results showed that there was no AE activities on the pipe without leak while for the pipe with leak, the AE activities are greater for full close valve than full open valve. In addition, two equations for locating the source of the pipe leak were introduced from the RMS against distance graft. For the pipe with leak and full open valve, the equation is $y = 0.011x + 0.249$. For the pipe with leak and full close valve, the equation is $y = 0.017x + 0.199$.

ABSTRAK

Projek ini dijalankan sebagai satu kajian tentang lokasi sumber kebocoran paip menggunakan teknik pancaran akustik (AE) satu siaran. Objektif projek ini adalah untuk mengkaji satu sistem yang berkesan dan berkebolehan dalam mengawasi kebocoran paip dan juga untuk mengetahui lokasi sumber kebocoran paip menggunakan teknik AE. Satu rig ujikaji terdiri daripada paip tanpa bocor dan paip bocor telah dibina menggunakan paip besi galvani berlilitan bulat untuk menjalankan eksperimen ini. Bendalir yang digunakan sepanjang eksperimen ini ialah air. Aliran air dikawal oleh injap bola. Sumber isyarat AE adalah daripada kebocoran paip itu dan ianya dicerap dengan menggunakan penderia AE dengan bantuan paparan dari perisian Acoustic Emission Detector 2.1.3. Untuk semua keadaan paip, nilai-nilai ‘hits’, ‘counts’ dan RMS (purata, maksimum dan minimum) telah direkod dan dianalisis. Semua nilai yang direkod telah dibandingkan antara paip tanpa bocor dan paip bocor (bukaan penuh injap dan tutupan penuh injap). Keputusan diperoleh daripada 8 titik yang ditanda pada setiap keadaan paip. Keputusan menunjukkan bahawa tiada aktiviti AE berlaku pada paip tanpa bocor manakala untuk paip bocor, aktiviti AE adalah lebih tinggi untuk tutupan penuh injap berbanding bukaan penuh injap. Selain itu, dua persamaan untuk mencari lokasi sumber kebocoran paip diperkenalkan daripada graf RMS melawan jarak. Untuk paip bocor dengan bukaan penuh injap, persamaannya adalah $y = 0.011\,x + 0.249$. Untuk paip bocor dengan tutupan penuh injap, persamaannya adalah $y = 0.017\,x + 0.199$.

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LIST OF SYMBOLS

A	Amplitude
D	Duration
E	MARSE
E_y	Energy
k	Kurtosis
μ	Dynamic viscosity
N	Counts
σ	Standard deviation
P_s	Pressure
ρ	Fluid density
R	Rise time
r	Internal resistance
t	Time
V	Voltage
V_{peak}	Peak amplitude
V_{rms}	Average voltage
ΔV	Velocity change
x	Distance
$\bar{x}$	Mean value
y	RMS
y_{rms}	RMS amplitude

LIST OF ABBREVIATIONS

AE	Acoustic emissions
A/D	Analog to digital
D/A	Digital to analog
MARSE	Measured area under the rectified signal envelope
NDE	Non destructive evaluation
NDT	Non destructive testing
PC	Personal computer
RMS	Root mean square
SCC	Stress corrosion cracking

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Transporting liquids through piping systems is a common practice. The term piping system is not new and practically every person has used one. During the past decade, stainless steel pipeline has been used for major transportation of fluid systems in many industries which is very important in daily life (Rocha, 1989). Without this proper technology, there will be a lot of problems faced by the administrators that can reduce the performance of the systems. For the general public there is very little understanding of the phenomenon behind the use of piping systems. Perfect piping will probably be forever elusive and pipe leaks will likely be always. The stainless steel pipes in water distributions and transmission systems are difficult to inspect for damage due to the location below the surface of the ground. High pressure and high temperature operating condition causes stainless steel pipe leaking when it is operated for few years. In some applications, like power plants, the failure of piping systems can cause severe economic losses and in worst cases the loss of human lives (Makar et al., 2001).

Leaks can occur from small holes caused by corrosion up to catastrophic pipeline failure due to manmade damage or natural causes such as an earthquake or a tsunami (Huebler, 2000). Because of this matter the development of pipe leak monitoring was introduced and research will keep running to improve the system from time to time. If the surface of the pipe is exposed, the location of the leak or crack can sometimes be determined by visual technique. But if the pipe is coated or buried, the location of the leak or crack is difficult to be determined by visual technique.

Therefore, several non destructive testing (NDT) techniques have been applied for this application to detect earliest leaking condition. Three conventional techniques are generally used including visual inspection using penetrate material, hydrostatic testing and ultrasonic testing (Huebler, 2000). These methods provide inadequate sensitivity and time consuming. For that reason, acoustic emissions (AE) technique incorporate with hydrostatic testing has been proposed to replace conventional technique. The advantage of using AE technique is that it provides sufficient sensitivity to detect a micro leaking propagation in material.

In this project, AE technique was used to monitor the leak of the pipe. If a leak occurs or propagates further, AE technique evaluates the possibility of leaks and further developments by detecting elastic waves that are generated inside the material. Unlike conventional non destructive tests, AE technique can inspect equipments in operation, detect a defect from far distance, recognize locations and monitor at any time given. Thus, it is an effective technology in inspecting and monitoring large equipments such as high temperature pipes in fossil power plants. Moreover, it can minimize the negative impact from removal of lagging materials around the pipe so that it performs an effective inspection with economically low costs.

1.2 OBJECTIVE

The objective of this project is to study a reliable and affordable system capable of monitoring acoustic signals for pipe leak. Once a practical understanding of the background acoustic signals is develops, the goal of this project is to isolate and identify signals from the background that are caused by an infringement, a leak, or damage which could at a later date cause a leak. The major objective of this project is to locate the source of the pipe leak using AE technique.

1.3 SCOPE OF THE STUDY

The use of scope is to ensure that the project is done towards the right direction and achieved the objectives stated. For this project, the study will base on the development of pipe leak monitoring using AE technique. Two pipes are used where one is the pipe with leak and other is the pipe without leak. Practically, the AE signal generated is investigated and analyzed to determine the micro leaking initiation. Beside, the AE signals will be analyze in order to locate the source of the pipe leak.

1.4 IMPORTANT OF THE STUDY

This study is needed to be done to provide an effective technique in determining the pipe leak. It also can be use as an important reference for further research in analysis of AE characteristics or parameters to be used in pipe leak monitoring. The successful of the study will provide a great achievement in development of pipe leak monitoring using the AE technique.

1.5 DISSERTATION ORGANIZATION

To complete this dissertation, several chapters are divided. The chapters are organized according to the flow for better understanding of readers. The organization is show as below:

Chapter 1	:	Introduction
Chapter 2	:	Literature Review
Chapter 3	:	Methodology
Chapter 4	:	Result and Discussion
Chapter 5	:	Conclusion and Recommendation

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, it is all about and clearly related to the problem statements. Failure modes, crack characterization, acoustic emissions (AE) technique, others technique for pipe leak monitoring and also a few reviews of primary research that had been done will be briefly explained for basic understanding. All of this information will help for further study and analysis. This chapter is very important to build the basic knowledge of this project.

2.2 FAILURE MODES

Numbers of water pipelines failures are being reported throughout the world. Causes of failures are very complex, varied and can be related to age, pipe materials, ground conditions and the pipeline construction. In most cases, failures are affected by two or more factors.

Failure modes refer to the actual manner in which the pipes fail, rather than the mechanism that causes the failure. These modes vary depending on the diameter of the pipe. Smaller diameter pipes have lower water pressure but also smaller moments of inertia which makes them tendency to longitudinal bending failures. Larger diameter pipes have higher water pressure and higher moments of inertia producing a tendency to longitudinal cracking and shearing at the bell (Makar et al., 2001).

According to Wei Qiao and Vipulanandan (2008) in their study of “Crack Analysis of Steel Water Pipelines”, water pipeline failure modes include blowout holes, circumferential cracking, bell splitting and longitudinal cracking. Corrosion plays an important role in the mode of blowout holes while circumferential cracking was reported to be the most common failure mode for small diameter gray cast iron pipes (Makar et al., 2001).

2.2.1 Blowout Holes

Corrosion plays a role in many mechanical failures. However, corrosion by itself or with internal water pressure can also cause pipe failures. In this case corrosion pitting occurs until the pipe wall has thinned to the point where the water pressure blows out the remaining very thin pipe wall. This type of corrosion failure may produce a very small hole or a large one depending on how localized the corrosion process has been and the pressure experienced by the pipe.

2.2.2 Circumferential Cracking

Circumferential cracking is the most common failure mode for small diameter (<380 mm diameter) gray cast iron pipes. Typically, this type of failure is caused by bending forces applied to the pipe. The resulting failure occurs in a manner similar to a swig snapping, with the failure crack propagating across the circumference of the pipe. This type of failure may also be caused by soil movements producing tensile forces on the pipe, producing a simple tensile failure.

2.2.3 Bell Splitting

This failure mode also appears to be most common in small diameter pipe. Joints in cast iron pipes were originally sealed using rope packed between the bell of one pipe and the spigot of the other. Molten lead was then poured into the joint to complete the seal. Leadite, a rigid, sulphur based compound was used in the 1930s and 1940s as the substitute for lead. However, as a non metallic compound, leadite has a different thermal coefficient of expansion than lead. Consequently, very cold temperatures at the pipe can cause the bell to split. This failure mode is different from the longitudinal splitting both because of different causes and because the crack terminates just below the bell of the pipe once the stresses produced by the thermal expansion have been relieved.

2.2.4 Longitudinal Cracking

Longitudinal cracking usually appears to large diameter pipes. This failure mode may be due to internal water pressure, to crushing forces acting on the pipe or possibly to compressive forces acting along the pipe. Any of these loadings could result in a longitudinal crack. Once the crack has initiated, it may travel the length of the pipe. In some instances cracks have formed on opposite sides of the pipe. The end result has been the removal of a section of the top of the pipe.

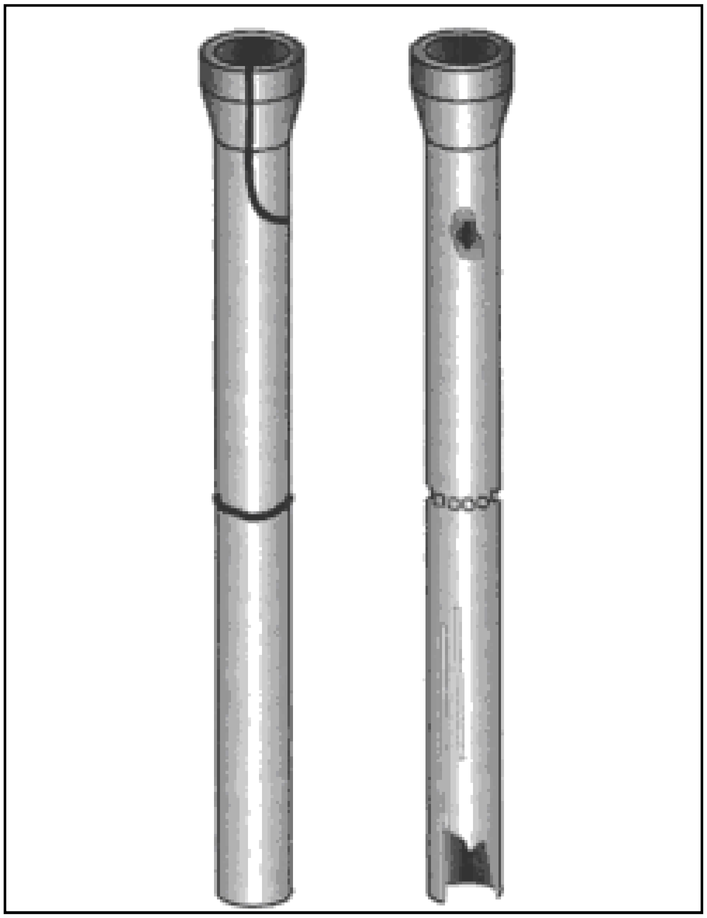

Figure 2.1: Failure modes for small (<380 mm) diameter pipe

Source: Underground Infrastructure Research (2001)

As shown in Figure 2.1, the left pipe showed bell splitting at the top of the pipe and circumferential cracking at the middle of the pipe. For the right pipe showed that the corrosion through hole at the top of the pipe, chain created corrosion pitting at the middle of the pipe and elongated corrosion pitting with blowout hole at the bottom of the pipe.

2.3 CRACK CHARACTERIZATION

Leaks can occur from small holes caused by corrosion up to catastrophic pipeline failure due to manmade damage or natural causes such as an earthquake or a tsunami. Leaks are actually very common and are classified as to the urgency of repair based on their potential danger. Typically they are classified into three groups, those that need repair in 24 to 48 hours, those which need to be repaired in 30 days, and those that do not need immediate repair, but should be monitored (Huebler, 2000).

From leaks can cause a crack. A crack may be invisible to the eye, but it can damage the pipeline sufficiently to cause a catastrophic failure by bursting. Moreover, cracks may develop in pipelines at any time. When cracks occur, there will be a lot of problems faced. Because of that, it is very important to avoid these cracks.

From the review by GE Power Systems Oil & Gas, there are many types of crack in pipeline systems. Every type of cracks has their own characteristics and the bad effects to the pipeline systems which explained below. During the pipeline operation, existing defects may grow due to fatigue.

2.3.1 Stress Corrosion Cracking (SCC)

External stress corrosion cracking on high pressure pipelines is recognized in two forms which are in high pH and in near neutral pH. Basically, the corrosion creates a crack aligned at right angles to the principal stress. External stresses such as ground movement can give rise to cracks at almost any angle through to fully circumferential. Other key factor that controls the rate of crack growth is temperature. The crack growth rate increases with temperature if all other conditions remain constant.

2.3.2 Fatigue Cracks

Metal fatigue is caused by repeated of varied stresses whose maximum value is less than the tensile strength of the material. The cracks start and grow steadily in reaction to pressure cycling, physical deformation of the pipeline and other mechanical stresses. This type of crack also known as the toe cracks.

2.3.3 Laps

These defects originate during the rolling process used to produce the plate or strip from which pipe is fabricated. Surface cracks in the hot slab become oxidized which prevents them from welding to the adjoining metal during later rolling. The cracks remain on the outer layer of the steel and are rolled over to become surface breaking defects at a very shallow angle. They can occur in any position around the pipe.

2.3.4 Hook Cracks

These defects in the longitudinal weld occur during manufacturer of the pipe when the plate edges are turned out of the plane of the steel during the welding process. They may pass the manufacturer's initial hydro test but fail later due to metal fatigue. It is the turning out of the metal at the weld that gives the characteristic hook shape to the crack.

2.4 ACOUSTIC EMISSIONS (AE) TECHNIQUE

Rocha (1989) found that only relatively low frequency acoustic signals are useful for practical leak detection techniques. Acoustic frequencies on the order of 10 Hz can propagate in the gas for distances on the order of 100 miles.

Acoustic emissions are the stress waves produced by sudden internal stress of materials caused by changes in the internal structure. Possible causes of the internal structure changes are leak initiation and growth, leak opening and closure, dislocation movement and fiber breakage. The detection of these emissions is usually used to predict material failure because most of the sources of AE are related to each other.

Acoustic emissions move as a stress waves with the absent of a medium. The medium can be various types of things which are usually depending on the parameter and the subject that need to be analyzed. In this project, the wave propagation medium can be the leak itself, the fluid and also the pipe’s wall. Piezoelectric sensors along with amplifiers are used to measure various parameters in AE testing. AE technique is a dynamic inspection method and qualitatively examines the defects.

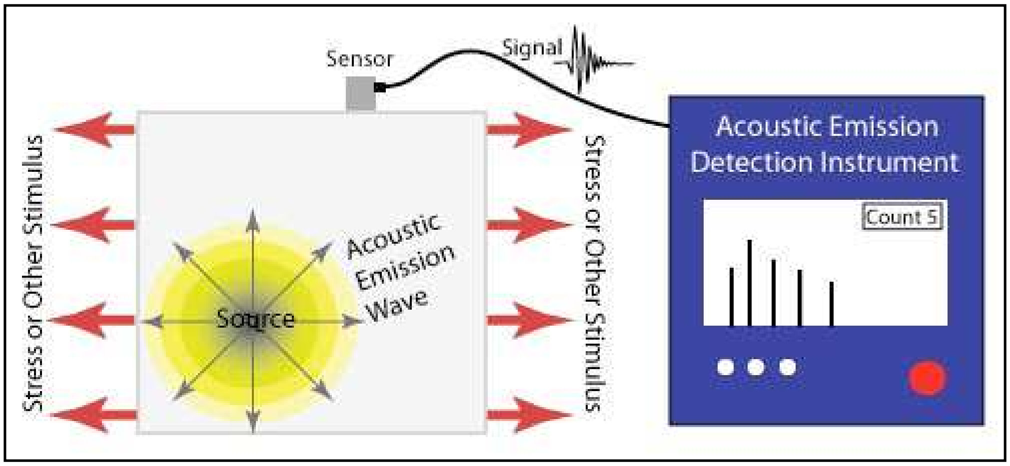

Figure 2.2: The source of acoustic signal

Source: NDT Resource Center

2.4.1 Pipeline Leak Detection Installation

There are several commercial companies who have installed and operated acoustic leak detection systems. They claim a low false alarm rate and capability of leak detection in both gas and liquid pipelines. As their method is proprietary no information is available on their technology.

Basically, acoustic emissions testing can be performed in the field with portable instruments or in a stationary laboratory setting. Typically, systems contain a sensor, preamplifier, filter and amplifier along with measurement, display and storage equipment such as oscilloscopes, voltmeters and personal computers. Acoustic emissions sensors respond to dynamic motion that is caused by an AE event. This is achieved through transducers which convert mechanical movement into an electrical voltage signal.

Ideally, the AE signal that reaches the mainframe will be free of background noise and electromagnetic interference. Unfortunately, this is not realistic. However, sensors and preamplifiers are designed to help eliminate unwanted signals. First, the preamplifier boosts the voltage to provide gain and cable drive capability. To minimize interference, a preamplifier is placed close to the transducer.

Next, the signal is relayed to a band pass filter for elimination of low frequencies which are common to background noise and high frequencies. Following completion of this process, the signal travels to the acoustic system mainframe and eventually to a computer or similar device for analysis and storage.

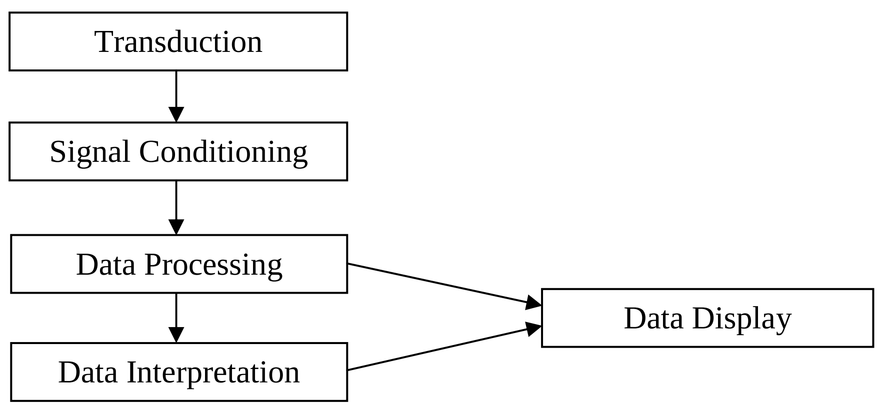

Figure 2.3: The AE system

Source: Waves in Solids LLC

2.4.2 Sensors for Detecting Pipeline Leaks

Historically, various types of sensors have been employed to detect acoustic signals emitted by gas escaping through a leak or emitted by structural impact or failure of the pipe wall. A detailed description of the technique of operation of acoustic sensors is given by Sinha (2002). Such sensors must be very responsive to dynamic signals, have a wide frequency response, and be robust and dependable.

Accelerometers have been widely used to detect acoustic signals in a pipeline by coupling the sensors to the pipe wall or to the surrounding soil. The sensor portion of the accelerometer is usually a piezoelectric crystal that is highly sensitive to accelerations due to vibrations. Minute vibration amplitudes of the crystal result in a tiny electric current output that can be highly amplified to produce an excellent dynamic instrument. Accelerometers can easily measure signal frequencies on the order of hundreds of kilohertz. The limitation of the dynamic response is generally limited by the inertia of the article to which the instrument is coupled.

Foil strain gages applied to the pipe wall are also used to sense the vibration modes of the pipeline in response to an infringement event. While less expensive than accelerometers, in general, foil strain gages do not have the dynamic frequency response exhibited by piezoelectric accelerometers. Vibrating line strain gages detect the change in frequency of a taut line stretched between two anchoring points on the pipe wall.

Microphones have been widely used to detect the acoustic signal in the gas in the pipeline. Microphones consist of varying types and configurations but all must be capable of maintaining sensitivity in a high ambient pressure. Microphone types consist of crystal transducers, capacitive transducers, inductive transducers, magnetic transducers and strain sensitive transducers. The response of the microphones to acoustic signals is characterized by the dynamics range, frequency response, and directionality of the device (Hall, 1980).

Dynamic pressure transducers can also be used to detect the acoustic signal in pipelines. The sensing element of such transducers is usually piezoelectric. The pressure transducers are coupled to the gas but may also inherently respond to acoustic signals transported by the pipe wall if the transducer is rigidly mounted to the pipe by a standard pipe fitting connection.

Some researchers in acoustic leak detection have used optical methods to detect leaks. Jette et al. (1977) compared the results of an earth coupled accelerometer with a laser interferometer configured to measure the local displacements of the ground above the pipe transporting an acoustic signal. The results were promising since the laser based system could detect smaller ground surface displacement amplitudes than the accelerometer used.

2.4.3 Types of Acoustic Emissions

The appearance of a rupture, leak or damage that could cause a leak usually generates an acoustic signal. During the leak initiation and early leak growth, the steel pipe wall deformation creates a significant acoustic signal that can produce a transducer output ranging from several micro volts to several volts. The amplitude and frequency spectrum and the attenuation behavior are all a function of the pipe wall material properties (Bassim and Tangri, 1984). If damage causes a sudden leak, then the associated rapid change in fluid pressure produces a pressure transient often referred to as a burst signal.

In summary there are three types of signals associated with a pipeline system which are as follows (Rocha, 1989):

1. A step (burst signal) function produced by the onset of a leak.
2. A ramp function resulting from step function signal attenuation.
3. A wide range of frequencies produced by the escaping supersonic jet.

For this project, two types of acoustic signal were mainly detected which are burst signal and continuous signal. Burst AE signal is a qualitative description of the discrete signals related to individual emission events occurring within the material. On the other hand, continuous AE signal is a qualitative description of the sustained signal produced by time overlapping signals.

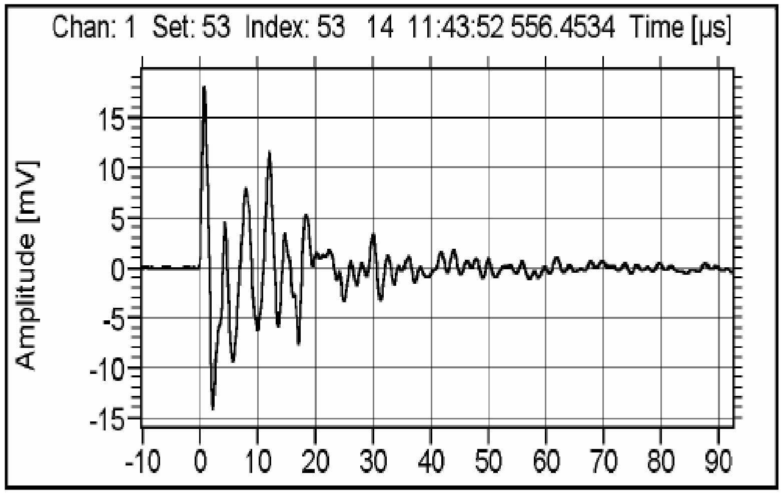

Figure 2.4 (a): Burst AE signal

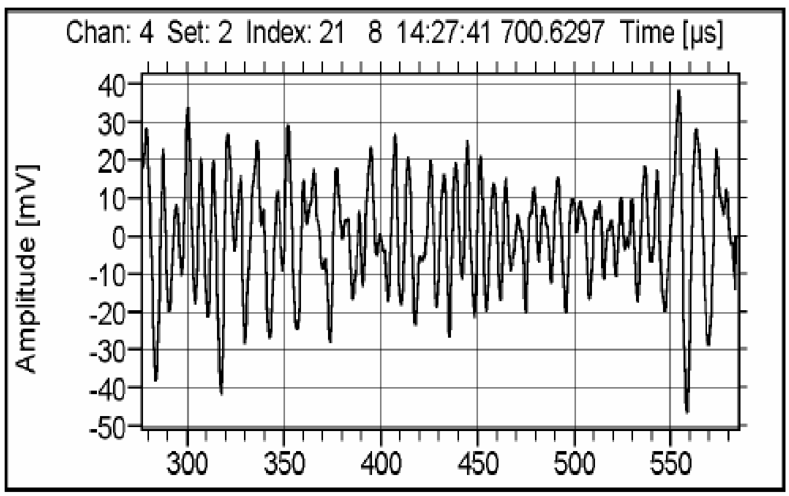

Figure 2.4 (b): Continuous AE signal

Source: AE Testing Fundamentals, Equipment, Applications

2.4.4 Acoustic Emissions Parameters

Usually, the signals which were excited by the induced stresses in the pipelines system were monitored and analyzed. When a useful transient or burst signal is correctly obtained, parameters like amplitude, counts, measured area under the rectified signal envelope (MARSE), duration and rise time can be gathered.

Amplitude, *A*, is the greatest measured voltage in a waveform and is measured in decibels (dB). This is an important parameter in acoustic emissions inspection because it determines the ability to detect the signal. Signals with amplitudes below the operator defined and minimum threshold will not be recorded.

Counts, *N*, refer to the number of pulses emitted by the measurement circuitry if the signal amplitude is greater than the threshold. Depending on the magnitude of the AE event and the characteristics of the material, one hit may produce one or many counts. While this is a relatively simple parameter to collect, it usually needs to be combined with amplitude and/or duration measurements to provide quality information about the shape of a signal.

MARSE, *E*, sometimes referred to as energy counts, is the measure of the area under the envelope of the rectified linear voltage time signal from the transducer. This can be thought of as the relative signal amplitude and is useful because the energy of the emissions can be determined. MARSE is also sensitive to the duration and amplitude of the signal, but does not use counts or user defined thresholds and operating frequencies. MARSE is regularly used in the measurements of acoustic emissions.

Duration, *D*, is the time difference between the first and last threshold crossings. Duration can be used to identify different types of sources and to filter out noise. Like counts, *N*, this parameter relies upon the magnitude of the signal and the acoustics of the material.

Rise time, *R*, is the interval between the first threshold crossing and the signal peak. This parameter is related to the propagation of the wave between the source of the acoustic emission event and the sensor. Therefore, rise time is used for qualification of signals and as a criterion for noise filter.

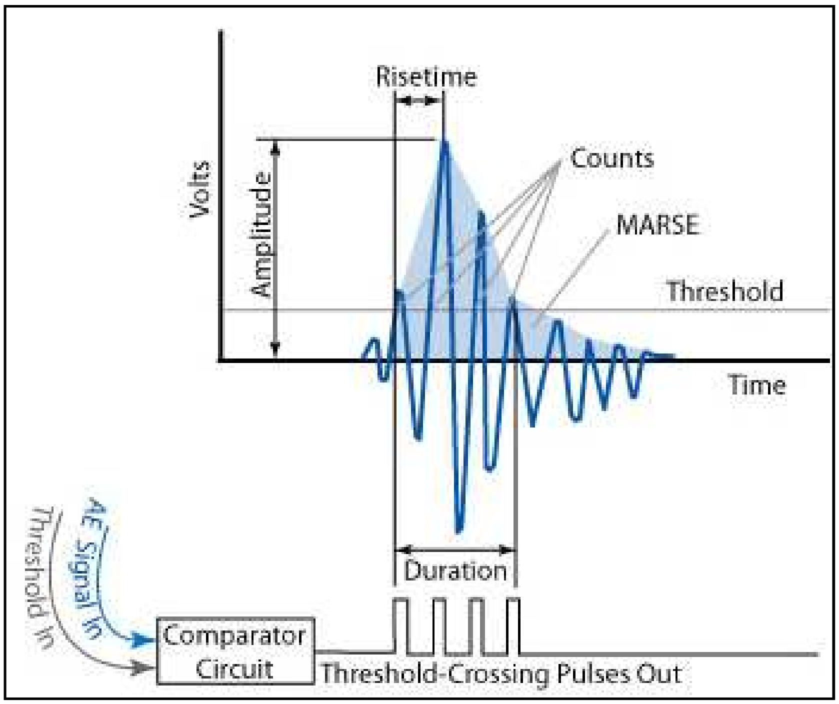

Figure 2.5: AE signal feature

Source: NDT Resource Center

2.4.5 Signal Processing

Basically, signals may be classified as multi channel and multi dimensional, continuous time and discrete time, continuous valued and discrete valued and deterministic signals and random signals. Signals may be processed by appropriate analog system which is called the analog signal processing or may be processed digitally which is called the digital signal processing. An analog signal may be converted to a digital signal by using analog to digital (A/D) converter while a digital signal may be converted to analog signal by using a digital to analog (D/A) converter (Proakis and Manolakis, 1996).

Nowadays, non destructive evaluation (NDE) data is analyzed not only in the time and frequency domain but also in the amplitude domain and phase domain to extract as much information from the signal as possible. Digital filters are used to improve the signal-to-noise ratio and time series modeling is some of the recent techniques, used in acoustic techniques of NDE. The success of leak detection by AE technique depends on three factors (Huebler, 2002):

1. Nature of acoustic emissions radiated from the leak.
2. Attenuation between the leak and the sensor.
3. Background noise.

The physical origin of the leak signal is the fluctuating pressure field associated with turbulence in the fluid. The actual detection of the leak depends on the flow rate as this factor decides the energy content of the leak signal (Moorthy, 1992). The other alternative is intermittent monitoring and looking for a change in impedance of the pipeline. This will require an input of acoustic energy, such as a speaker (Watanabe et al., 1987).

The current generation of acoustic leak detection equipment uses two sensors which are fixed to the exterior or inside the pipeline with the leak signal coming from anywhere between these sensors. The leak signal received by both sensors is received at different times depending on their distance from the leak. The signals received by these sensors are transmitted to the same processor and are cross correlated. The cross correlation output indicates the difference in transmission time of the signal from the leak to each sensor.

The leak site can be located if the velocity of acoustic propagation in the pipeline is known. The pipe and its fittings either side of a leak acts as cascade of filters that attenuate some frequencies in the leak signal while letting other propagate. If the filtering is quite different either side of a leak, acoustic correlation techniques tend to fail. This can be remedied by equalization of the signals received at each sensor before cross correlation (Seaford, 1994).

2.4.6 Time Domain Analysis

In general, time domain analysis uses the time history of the signal. The signal is kept in a real time analyzer or an oscilloscope and any non steady or transient impulses are noticed. Discrete damages can be identified easily from the waveform. Normally, indices such as the peak level, root mean square (RMS) level and the crest factor are used to detect damage in pipe crack monitoring (Singiresu, 2003).

Since the peak level appears only one, it is not a statistical quantity and is not reliable parameter to detect damage. For the RMS value, although it is a better parameter to detect damage in steady state applications, it may not be useful if the signal contains information from more than one component.

Theoretically, the maximum amplitude or peak amplitude can be determined straightly from the signals. For continuous signal *y(t)*, the RMS amplitude can be defined as equation:

$$y_{rms} = \sqrt{\frac{1}{t_1 - t_2}\int_{t_1}^{t_2} y^2 \, dt} \qquad (2.1)$$

Meanwhile for the same continuous signal *y(t)*, the energy can be given as:

$$E_y = \int_{-\infty}^{\infty} |y\ (t)|^2\ dt \tag{2.2}$$

On the other hand, the crest factor is defined as the ratio of the peak to RMS level, includes information from both the peak and the RMS levels. The crest factor is suitable for identifying cracking initiation and grows and defined as:

$$Crest\_factor = \frac{V_{peak}}{V_{rms}} \tag{2.3}$$

For pipe crack monitoring, the moments of the probability density curve can be used. The first four moments of a probability density curve are known as the mean, standard deviation, skewness and kurtosis, respectively (Singiresu, 2003). For practical signal, the odd moments are usually close to zero and the even moments denote the impulsiveness of the signal. The kurtosis is defined as:

$$k = \frac{1}{\sigma^4} \int_{-\infty}^{\infty} (x - \bar{x})^4 f(x) dx \tag{2.4}$$

Where *f(x)* is the probability density function of the instantaneous amplitude, *x(t)*, at time *t*, $\bar{x}$ is the mean value, and σ is the standard deviation of *x(t)*.

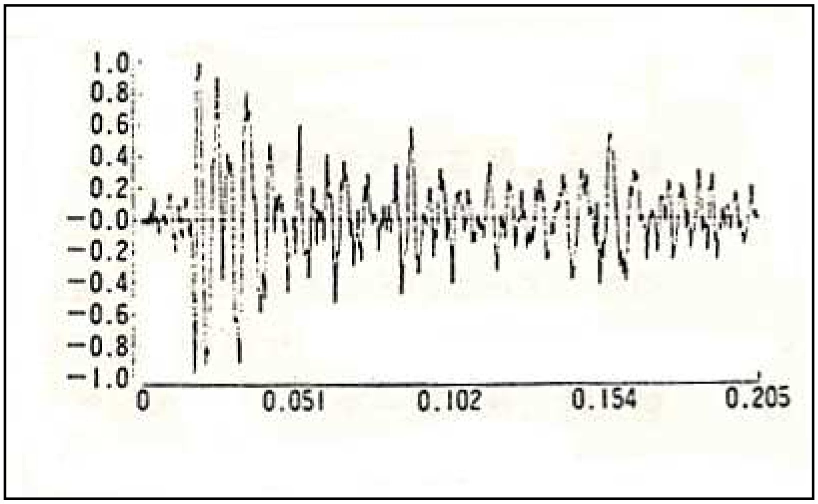

Figure 2.6: Time domain

Source: Waves in Solids LLC

2.4.7 Frequency Domain Analysis

The frequency domain signal is also known as the frequency spectrum. The signal is a plot of the amplitude of vibration response versus the frequency and can be derived by using the digital fast Fourier analysis of the time waveform (Singiresu, 2003). The frequency spectrum provides important information about the condition of a pipe system. As long as the excitation forces are constant or vary by small amounts, the measured vibration level of the machine also remains constant or varies by small amounts. However, as the pipe starts developing damages, its vibration level and the shape of the frequency spectrum changes. The nature and location of the damage can be detected by comparing the frequency spectrum of the pipe system in damaged condition with the reference frequency spectrum corresponding to the pipe system in good condition.

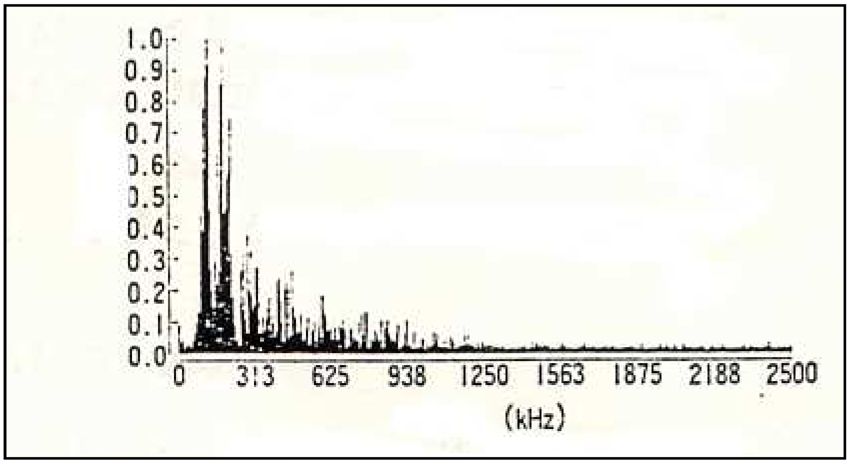

Figure 2.7: Frequency domain

Source: Waves in Solids LLC

2.4.8 Benefits of AE Technique

Compared to other monitoring techniques, the AE technique gives a lot of advantages. First of all is global monitoring. Sensors detect AE signals from considerable distances, making this technique ideal for global monitoring of large vessels and systems. Identified problem areas can then be inspected using other non destructive test techniques.

Second is minor disturbance of insulation. By using AE technique only small holes in insulation are required for sensor mounting. On high temperature applications, waveguides are used to contact the surface. Sensors are then mounted outside the insulation.

Besides, for most storage vessels, online testing is possible by filling it with product, introducing gas into the vapor space, controlling the temperature or other process parameters. This is another advantage of AE technique.

AE technique also cost reduction. The use of AE can reduce plant maintenance costs considerably, while increasing the information available about plant integrity. Plant downtime for inspection is also minimized.

Last but not least the benefit of AE technique is rapid inspection. The actual AE test takes a matter of hours, and in some cases, considerably less. No comparable technique can provide 100% volumetric inspection in the same amount of time.

2.5 OTHERS TECHNIQUE FOR PIPE LEAK MONITORING

Each technology has cost and development issues that must be solved before it becomes practical. Different techniques have their own advantages and also disadvantages. Therefore, it is important to choose the best technique that can provide the real and effective result in order to minimize the cost. Here, a few techniques were discussed for references according to Huebler (2002).

2.5.1 Visual Inspection and Sounding

The simplest technique is by visual inspection and sounding. The advantages of this technique are the longest record of successfully detecting damaged pipes and suitable to examine condition of concrete. This technique provides many disadvantages as requires man entry into pipes, does not give direct information on wire breaks, unclear whether all wire breaks will produce noticeable concrete damage and subjective in nature and dependent on skill of inspection team.

2.5.2 GPS System and Computerized Pipeline Maps

A leak detection technique which is known as GPS system and computerized pipeline maps also can be apply. The advantage is no equipment installed on the pipeline and the disadvantages are requires equipment on each piece of construction equipment and also requires equipment operators to maintain equipment.

2.5.3 Ultrasound

Ultrasound is a popular technique for monitoring pipe cracks. This technique is the most versatile NDE technique and established technology in oil industry. The advantage is the tests show that it can detect and size corrosion pitting while the disadvantages are the technique will not work through tuberculation, not yet commercially available for water lines and requires access to and complete cleaning of the inside of the pipe.

2.5.4 Magnetic Flux Leakage

Magnetic flux leakage technique can be used for pipe crack monitoring. This technique was established technology in oil and gas industry. It is also known to be capable of detecting small defects and through holes in steel pipe. The disadvantages are not yet commercially available for water lines and require access to and complete cleaning of the inside of the pipe.

2.5.5 Zone Water Audits

Zone water audits technique has many advantages and also disadvantages. This technique is cheap, covers large areas of a city quickly and allows for a comparison of water losses between individual districts. It also useful as a screening process for other techniques and can be used to evaluate the effectiveness of repair programs. The disadvantages of this technique are does not give the precise location of leaks, requires isolation of zones, work must be performed at night and only gives an overview of current problems.

Acoustic emissions technique is unlike most other non destructive testing (NDT) techniques in two regards. The first difference pertains to the origin of the signal. Instead of supplying energy to the object under examination, AE technique simply listens for the energy released by the object. AE tests are often performed on structures while in operation, as this provides adequate loading for propagating defects and triggering acoustic emissions.

The second difference is that AE technique deals with dynamic processes or changes in a material. This is particularly meaningful because only active features such as crack growth are highlighted. The ability to discern between developing and stagnant defects is significant. However, it is possible for flaws to go undetected altogether if the loading is not high enough to cause an acoustic event.

Furthermore, AE technique usually provides an immediate indication relating to the strength or risk of failure of a component. Other advantages of AE technique include fast and complete volumetric inspection using multiple sensors, permanent sensor mounting for process control, and no need to disassemble and clean a specimen.

2.6 REVIEWS OF PRIMARY RESEARCH

Through the research to gain information about this project, the most referred papers is by Rocha (1989) entitle “Acoustic Monitoring of Pipeline Leaks”. His leak detection technique is described clearly and seems very promising.

In his researched, the pressure sensors are used to record leak produced pressure waves in the range from 0.05 Hz to 10 kHz. He stated that only such low frequency waves were capable of traveling the large distances between pipelines system without excessive damping. He then applied a noise cancellation technique to eliminate the background noise. This technique required placing two such sensors a distance apart. For 61 meters he calculated the wave travel time between the sensors to be 153 milliseconds.

Furthermore, the sensors were made to distinguish the direction from where the wave originates. This is important for his technique of leak location. Feeding the upstream sensor output through a 153 milliseconds signal delay box and subtracting it from the signal of the downstream sensor cancelled out the background noise.

The first system employing expansion waves for leak detection was applied in 1972. The change in pipeline velocity, ΔV associated with sudden appearance of a leak causes an acoustic pressure wave signal of magnitude:

$$\Delta P = -\rho \times c \times \Delta V \tag{2.5}$$

Setting the effective area of the leak divided by that of the pipe by $(D_1 / D_p)^2$ and the fluid density, ρ proportional to the pipeline pressure, P_s allowed him to reduce this equation to:

$$\Delta P = 0.3\, P_s \left(\frac{D_1}{D_2}\right)^2 \tag{2.6}$$

By employing the noise cancellation technique with pressure peaks of about 200 mbar within 150 meters of the compressor, he was able to detect extremely small leak induced acoustic pressure waves as low as 5 mbar. From the difference in burst wave arrival time the leak location could be detected within $\pm$ 150 meter. In a 3 mile long test pipeline of 14 inches diameter, with flow rate of 3800 mscf of methane at a pressure of 75 psi he could locate a hole of 0.81 inches in diameter within 53 ft variance.

Jolly et al. (1995) reviewed several different acoustic based leak detection techniques and found the most promising technique is the low frequency impulse detection technique. The impulse technique uses sensors mounted at the ends of the pipeline.

This technique could capture the transient acoustic event associated with a rapid rupture event. This technique could only detect large size failures which are over one inch in diameter but then over distances up to 100 km. But the technique would not detect small leaks, which grow over several hours.

They found that when sensors are mounted on the outside of the pipe, to detect noise of a leak, the frequency range is typical in the range of 5 to 300 kHz. Detection range in a gas filled pipe is 2.5 times that of a liquid filled pipe. This technique is used only in industrial plants and typical detection ranges from 140 meters for a 2 gpm leak to 350 meters for a 200 cfm leak.

Min Lee and Joon Lee (2000) developed an acoustic emissions technique to detect pipeline leaks. In the researched, they used two different techniques for determining source location which are reduction in signal amplitude with increasing distance from the source and increase in signal transit time with increasing distance from the source. The first technique is attenuation based while the second technique is time of flight based. The signal generated by the turbulence of gas in the pipeline was found to be wide band signal having less than 600 kHz frequency. The leak in the pipeline generates acoustic waves which propagate along the pipe wall.

In the first technique which is the attenuation based technique, the RMS value of the high frequency sound transducer signal is the sum of noise RMS plus true RMS. In the second technique which is the time of flight based technique, the leak was detected by using the transit time difference between two test sensors.

For the researched, they did experiments on a 6 m long, 19 mm outside diameter and 1 mm in wall thickness with nitrogen gas at 5 and 10 kgf/cm^2 and 0.3 to 1 mm of holes drilled to simulate the leak. Four sensors were used with 150 kHz, 225 kHz, 500 kHz and one broadband type.

The signals detected by the sensors were amplified and then recorded. Next, the recorded signals were compared in the system with the corresponding background signal stored in the computer memory. The sensitivity of the system found to be decreased by increasing the spacing between the sensors and the measuring error was more than 7 percent. As the conclusion, the first technique which is the attenuation based technique was found to be more effective to detect leaks.

According to Jirapong Lim and Kaewkongka (2007) in his research stated that acoustic emissions technique incorporate with hydrostatic testing has been successfully developed for high pressure stainless steel pipe evaluation in petrochemical industries.

This technique employed 100 kHz and 300 kHz resonance acoustic emissions sensors that were mounted on the pipe material used which was stainless steel pipe specimen with 400 mm diameter. Various hydrostatic pressures starting from zero to 120 bars were applied to the pipe and AE signals from both sensors were captured by a personal computer via data acquisition card.

The crest factor and AE energy which are the processed AE parameters were used to indicate crack initiation or growth in the pipe material during pressurized. Six pieces of 5 years old stainless steel pipes from industry were tested in the experiment.

The test results presented that the proposed signal analyzing technique, the AE energy and crest factor can be used to indicate 2 defected pipes from totally 6 specimen pipes at difference applying pressure level. The AE energy can be calculated by equation:

$$AE_{Energy}(U) = \left[\frac{1}{r}\int_0^T V^2\,(t)dt\right]^{\frac{1}{2}} \tag{2.7}$$

Where R is internal resistance of instrument, V is the voltage from AE sensor and T is the time of the burst period. To identify the event of burst type AE signal that generated by material crack propagating, the crest factor is utilized by equation:

$$Crest\_factor = \frac{V_{peak}}{V_{rms}} \qquad (2.8)$$

Where V_{peak} is peak amplitude and V_{rms} is average voltage of AE signal energy.

Several micro cracks have been found in the both defected pipes by micro structure test. Therefore, the advantage of using AE technique is that it provides sufficient sensitivity to detect a micro cracking propagation in material.

Compared everything stated above for reviews of primary researched that had been done, each type of researched has its own advantages and disadvantages. All of the referred researches will help to build the pipe leak monitoring using AE technique.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This project was mainly about to develop a pipe leak monitoring using acoustic emissions (AE) technique. The experiment was conducted and referred to several applied thesis that had been done by others researchers. With a little different approach, the experiments were conducted in order to get the results and achieve the objectives.

3.2 TEST RIG AND TOOLS PREPARATION

Basically, the experiments involved the usage of measurement tools which were the broadband acoustic sensor and preamplifier. The experiments were done to get the acoustic signal from the pipe with leak and the pipe without leak. The signals also were analyzed to locate the source of pipe leak. Full explanation on the test procedures will be mentioned in next topic. Only two pipes were used which were the pipe with leak and the pipe without leak.

For the pipe with leak, the leak itself was made by drill a small hole by using the drilling machine. This is the fastest way to produce the leak. Although the leak is not naturally made, it is still can be accepted for this experiment. The leak was drilled at a distance of 85 cm from the end of one pipe with diameter of 2.5 mm.

Figure 3.1: Drilled hole using drilling machine

Figure 3.2: Hole as the source of the leak

The flow of water through each pipes were controlled by a ball valve. The ball valve was connected to the end of the pipe. The ball valve was used for the pipe with leak where two conditions were applied, the full open valve and the full close valve.

Figure 3.3: Ball valve

Figure 3.4: Galvanized steel pipe, ¾ inches of diameter and 1 meter long

In this project, the fluid used was water with the properties of saturated water at 20^oC, density, ρ = 1000 kg/m^3 and dynamic viscosity, μ = 1.002 x 10^{-3} kg/m.s (Cengel and Cimbala, 2005). The water was pumped and let to flow through the pipe, either the pipe with leak or the pipe without leak by adjusting the control valve. The water flowed back into the tank and then continues to circulate through the same path.

Figure 3.5: Hydraulic bench

Figure 3.6: Pump

Typical of AE apparatus consist of various components. First of all is the sensor which was used to detect AE event. The function of the sensor is to convert the acoustic wave energy emitted by the source into usable electric signal typically voltage time signal. Another tool is preamplifier. Preamplifiers were used to amplify initial signal. Preamplifier is the first stage of the instrumentation system and its main function is to enhance the signal level against noise. Since the sensor produces charge proportional to the source intensity, the preamplifier must be located near the sensor. Hence normally a preamplifier is used along with the transducer and the two together forms the front-end of the acoustic emission instrumentation. Typical amplification gain is about 40 dB. The right choice of gain was needed to make sure the optimum errors.

Meanwhile, filter plays an important role in allowing the amplified signal from sensor and attenuating unwanted noise. An ideal filter of passive or active network allows the desired frequencies with unit gain and rejects unwanted frequencies. Filters are also designed for different bandwidth and can be plugged to preamplifier to meet the specific requirements. Beside, data acquisition device performs filtration, signal's parameters evaluation, data analysis and charting.

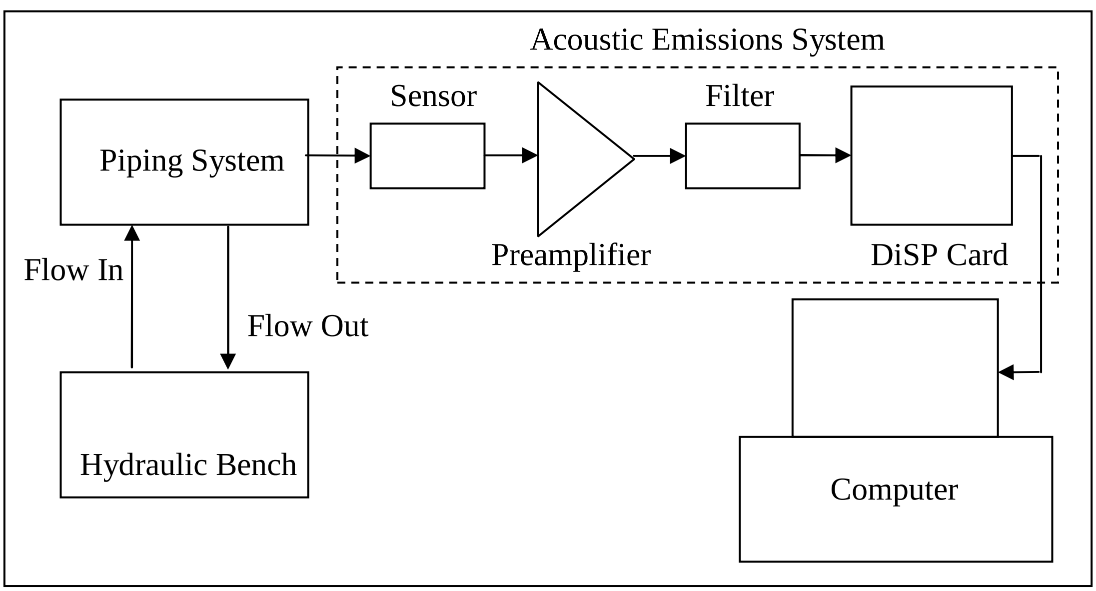

Figure 3.7: Typical of AE apparatus

Purpose of AE sensors is to detect stress waves motion that cause a local dynamic material displacement and convert the displacement to an electrical signal. The AE sensor was located at few points on the pipe line according to the test conducted. In order to measure the acoustic signal, the sensor must touch the pipe surface. To reach maximum detection, the grease was used between the AE sensor and the pipe. The AE sensor was taped at the location of interest (Zohari, 2008).

The AE sensor that used was a broadband acoustic sensor. This type of sensor was made by piezoelectric material. There were several types of sensor which were classified by its operating frequency. For this project, the sensor had the optimum frequency of 400 kHz. An integral preamp AE sensor, i400 with 400 kHz resonance, 40 dB gain and BNC coax connector were used. MAG-1 is the magnetic attachment for Model i400 integral preamp sensor while Coax25 is the Coaxial RG-58 cable, 25 feet and BNC coax connector.

Figure 3.8: AE sensor

For analysis of data from acoustic emission signal, AED-2000V Virtual Instrument was used as it is designed to work with Windows-based PC to provide complete setup and data acquisition control, real time graphics and data storage. The instrument includes new features such as parametric inputs, alarm outputs and external hold. It also provide single channel virtual acoustic emissions instrument with AC adapter (110 V/ 220 V) and 9 pin serial cable. The software that used to analyze the obtained acoustic signal is called Acoustic Emission Detector 2.1.3 software. The results from the software are shown in time domain.

Figure 3.9: AED-2000V Virtual Instrument

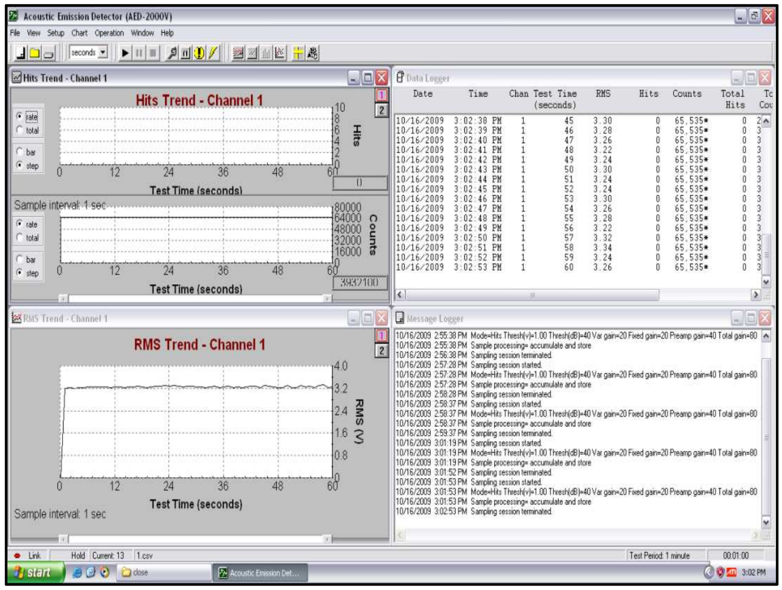

Figure 3.10: Acoustic Emission Detector 2.1.3 software

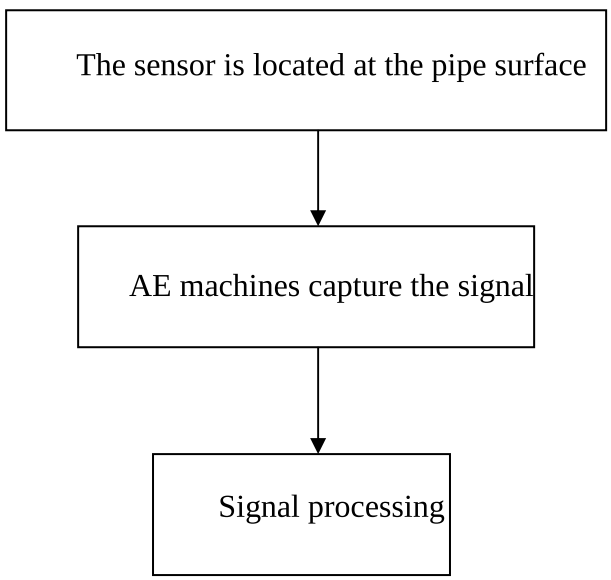

Figure 3.11: The hardware architecture

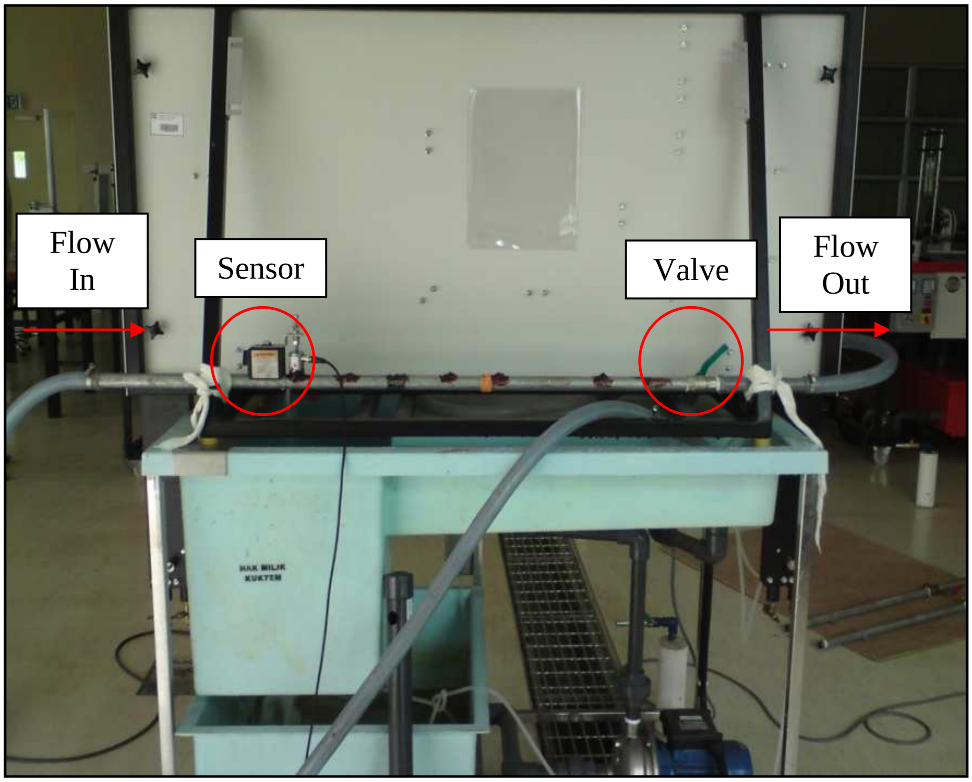

Figure 3.12: Test rig

Before the data can be taken, it is important to determine the value for the threshold. The try and error method is used to find the optimum value until the signal appears to the required form. For this experiment, the threshold for both hits mode and RMS mode was set fixed to 3.30 V and 50 dB.

3.3 TEST PROCEDURES

For this project, two test or experiments were conducted in order to get the results and achieve the objectives. The first test was to show and differentiate between two types of pipe which were the pipe with leak and the pipe without leak. The second test was to locate the source of the leak in the pipe. Both experiments were conducted by using acoustic emissions technique.

In the first experiment, an acoustic emission sensor was employed and attached on circumferential of a galvanized steel pipe specimen with ¾ inches of diameter and 1 meter long. 8 points were marked from the valve to the leak with the distance of 10 cm for each point. The hits mode from the Acoustic Emission Detector 2.1.3 software was set with the test period of 60 seconds.

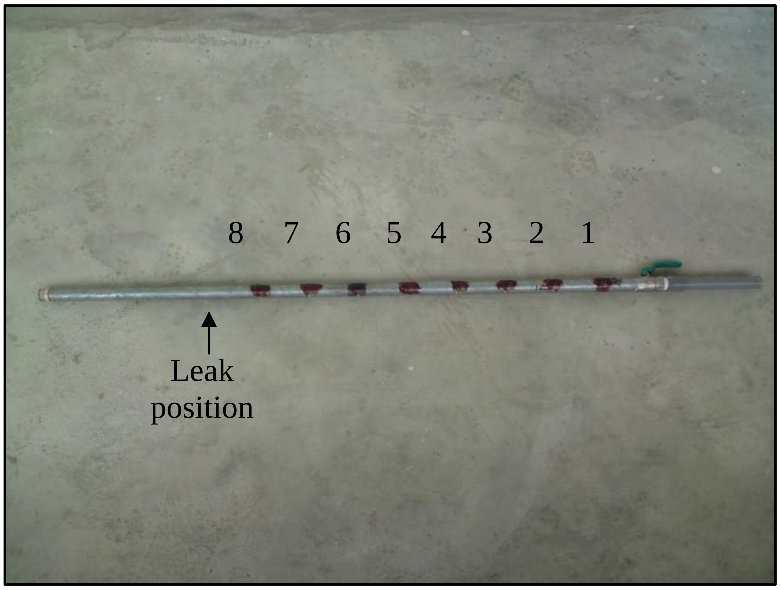

Figure 3.13: 8 marked points on specimen

The AE sensor used to detect the signal generated by the leak. Output signals from the AE sensor were amplified by preamplifiers. Then, the amplified signals were transmitted to data acquisition card which was installed in a personal computer and the time domain signals were recorded into the PC memory. Next, the hits mode was changed to the RMS mode with the same test period. For every point, the steps were repeated to get the data from each type of pipe which was the pipe without leak and the pipe with leak. For the pipe with leak, the flow of the water was controlled by the ball valve connected with the pipe with the full open valve and full close valve. The experiments were done with the pipe without leak, followed by the pipe with leak and full open valve and last with the pipe with leak and full close valve.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

As mentioned in the previous chapter, the experiment was conducted in order to differentiate the pipe with leak and the pipe without leak. Beside, the experiment was done to locate the source of the leak for the pipe with leak. Next topics show the results of the experiment. The example of acoustic emissions signals that viewed using Acoustic Emission Detector 2.1.3 software were as in the Appendix 1.

4.2 PIPE WITHOUT LEAK AND FULL OPEN VALVE

Table 4.1 and Figure 4.1 show the results from the experiment done on the pipe without leak and full open valve. The data were collected within 1 minute and then analyzed. The timer started after a few seconds, before the Acoustic Emission Detector 2.1.3 software collect the data. This is to ensure the signals measured are stable throughout the data collecting process. This condition applied for all the tests.

Table 4.1: Result from the pipe without leak and full open valve

POINTS	**HITS MODE**			**RMS MODE**		
	HITS	**COUNTS**	**RMS**	**AVG. RMS**	**MIN. RMS**	**MAX. RMS**
Point 1	0	0	0.058	0.049	0.028	0.099
Point 2	0	0	0.058	0.050	0.028	0.099
Point 3	0	0	0.060	0.051	0.027	0.099
Point 4	0	0	0.062	0.051	0.029	0.102
Point 5	0	0	0.062	0.052	0.030	0.100
Point 6	0	0	0.062	0.052	0.029	0.106
Point 7	0	0	0.062	0.052	0.032	0.103
Point 8	1	2	0.062	0.053	0.032	0.102

From the results gained for the pipe without leak and full open valve, the value of hits and counts for every point always zero accept at the last point. This is because at the last point, the point is near to the flow in water where the velocity of the water may affect the AE result.

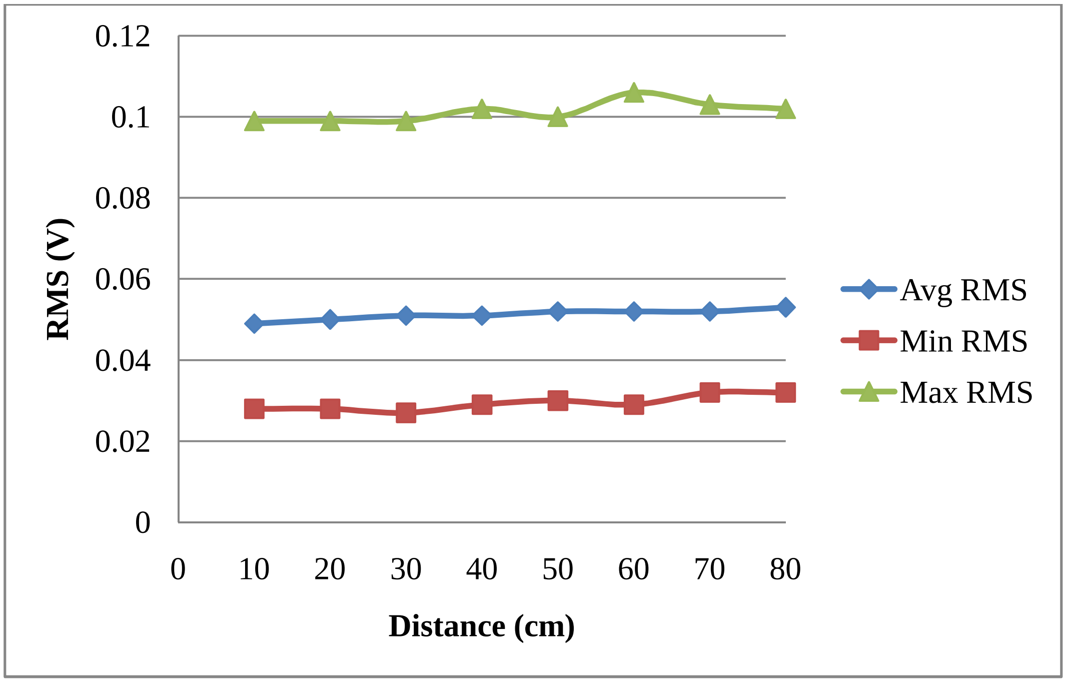

Figure 4.1: RMS mode for pipe without leak and full open valve

From the above graft, it shows that for the pipe with no leak and full open valve the variation of the RMS lines are approximately straight lines. The maximum RMS line is in the range of 0.099 – 0.102 V. The minimum RMS line is in the range of 0.028 – 0.032 V. The average RMS line is in the range of 0.049 – 0.053 V. The slightly small changes in the result showed that there were no AE activities during the experiment.

4.3 PIPE WITH LEAK AND FULL OPEN VALVE

Table 4.2 and Figure 4.2 show the results from the experiment done on the pipe with leak and full open valve. The data were also collected within 1 minute and analyzed. The data collected show that the value of AE parameters increase when the distance come to the source of the leak.

Table 4.2: Result from the pipe with leak and full open valve.

POINTS	MODE HITS			MODE RMS		
	HITS	COUNTS	RMS	AVG. RMS	MIN. RMS	MAX. RMS
Point 1	0	0	0.459	0.435	0.410	0.491
Point 2	20	21	0.464	0.481	0.451	0.547
Point 3	91	109	0.558	0.602	0.579	0.654
Point 4	123	135	0.636	0.604	0.588	0.657
Point 5	1288	1504	0.730	0.733	0.706	0.789
Point 6	9472	15817	0.838	0.768	0.740	0.826
Point 7	38768	284475	1.152	1.175	1.075	1.433
Point 8	36575	349470	1.170	1.231	1.168	1.318

From the results gained for the pipe with leak and full open valve, the value of hits and counts for every point were increase with the distance to the leak source. This is because, the nearest point to the leak source produced greater AE activities than the other points.

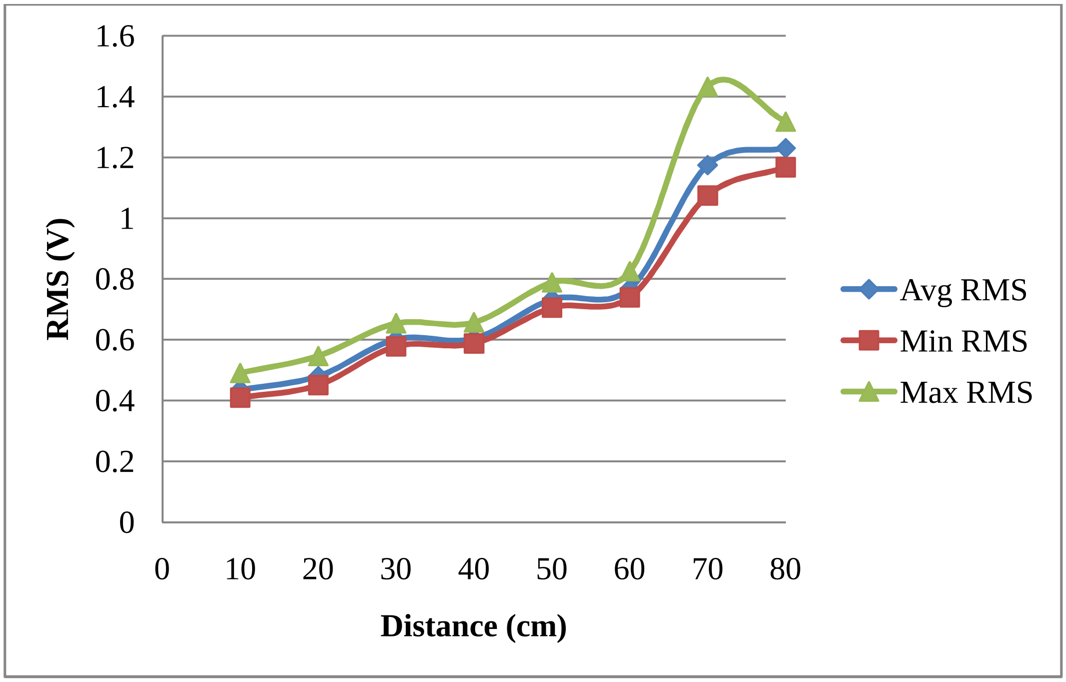

Figure 4.2: RMS mode for pipe with leak and full open valve

From the above graft, it shows that for the pipe with leak and full open valve the variation of the RMS lines are approximately increase with the distance to the leak. The maximum RMS line is in the range of 0.491 – 1.318 V. The minimum RMS line is in the range of 0.410 – 1.168 V. The average RMS line is in the range of 0.435 – 1.231 V. Sudden increase at Point 7 was because of the water circulation in the pipe during the experiment where the point just before the source of the leak.

4.4 PIPE WITH LEAK AND FULL CLOSE VALVE

Table 4.3 and Figure 4.3 show the results from the experiment done on the pipe with leak and full close valve. The data were also collected within 1 minute and analyzed. The data collected show the same variation with the pipe with leak and full open valve except that the values are slightly higher.

Table 4.3: Result from the pipe with leak and full close valve

POINTS	MODE HITS			MODE RMS		
	HITS	COUNTS	RMS	AVG. RMS	MIN. RMS	MAX. RMS
Point 1	2240	11522	0.340	0.378	0.301	0.504
Point 2	7686	128405	0.606	0.618	0.516	0.758
Point 3	13547	286443	0.813	0.772	0.666	0.907
Point 4	13400	343776	0.849	0.809	0.692	0.963
Point 5	18367	416225	0.906	0.856	0.746	0.994
Point 6	26828	492738	1.140	1.108	0.989	1.255
Point 7	28049	524291	1.510	1.526	1.394	1.679
Point 8	29484	818670	1.603	1.615	1.470	1.769

From the results gained for the pipe with leak and full close valve, the value of hits and counts for every point were increase with the distance to the leak source. This is because, the nearest point to the leak source produced greater AE activities than the other points. Compare to the pipe with leak and full open valve, the value of AE parameters were higher because the pressure when the full close valve was applied in the experiment.

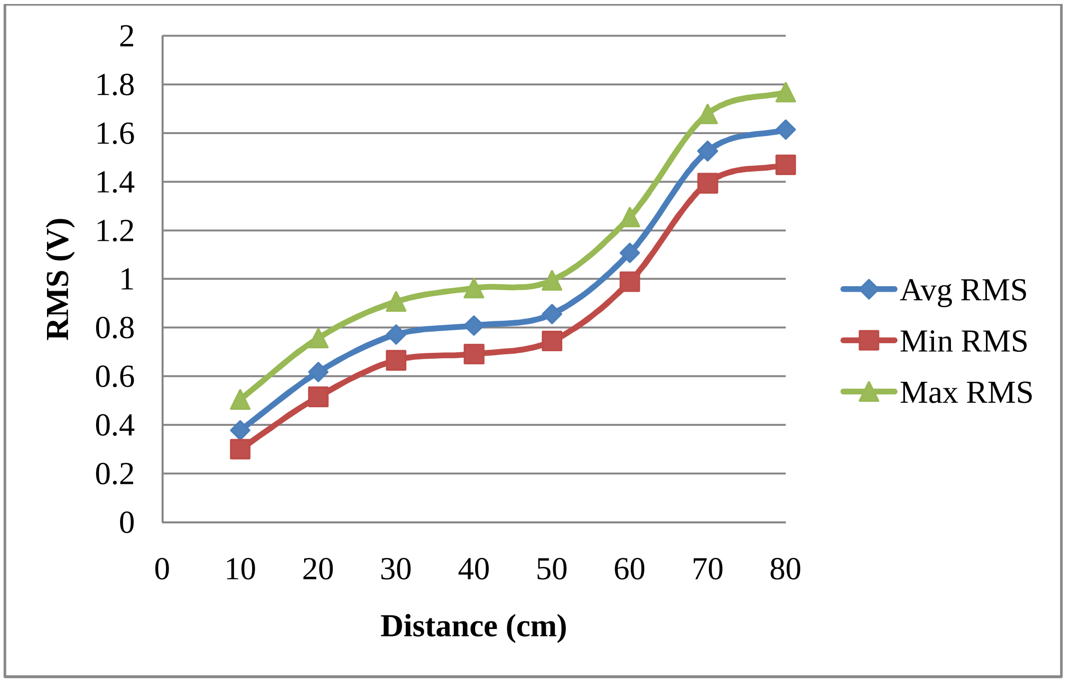

Figure 4.3: RMS mode for pipe with leak and full close valve

From the above graft, it shows that for the pipe with leak and full close valve the variation of the RMS lines are approximately increase with the distance to the leak and slightly higher than the pipe with leak and full open valve. The maximum RMS line is in the range of 0.504 – 1.769 V. The minimum RMS line is in the range of 0.301 – 1.470 V. The average RMS line is in the range of 0.378 – 1.615 V. The results were as expected where the greater AE activities occurred at the point near to the leak source.

4.5 COMBINED RESULTS

To see the different and the variation for each type of pipes done, the combined grafts from 'Hits Mode' were plotted. For this, hits, counts and RMS were considered from the pipe without leak and full open valve, the pipe with leak and full open valve and also the pipe with leak and full close valve.

4.5.1 Hits

Figure 4.4 shows that the variation of hits towards the distance of the leak. Basically, the value of hits will increase towards the point of the leak but if there is no leak, the value of hits will approximately zero.

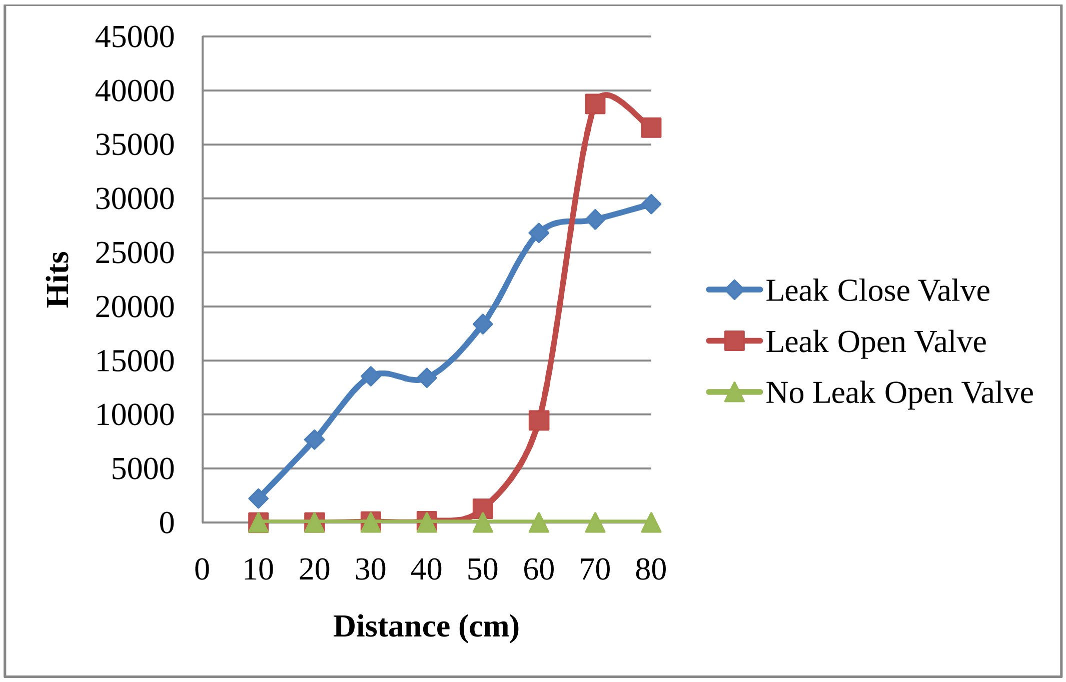

Figure 4.4: Hits against distance

From the above graft, it shows that the different of each type of pipe experiment in term of hits value. For pipe without leak and full open valve the value of hits are mostly zeros. This is because there are no AE activities in that pipe. For the pipe with leak and full close valve the value of hits are greater than the pipe with leak and full open valve for the first 6 points but the last 2 points the value of hits for the pipe with leak and full close valve is less than the pipe with leak and full open valve. This is because at those points, for the pipe with leak and full open valve the data collected was affected by the background noise where the sensor placed near to the flow out water. At that time, the flow out water produced some sound when hit with the hydraulic bench.

4.5.2 Counts

Figure 4.5 shows that the variation of counts towards the distance of the leak. Basically, the value of counts will increase towards the point of the leak but if there is no leak, the value of counts will approximately zero.

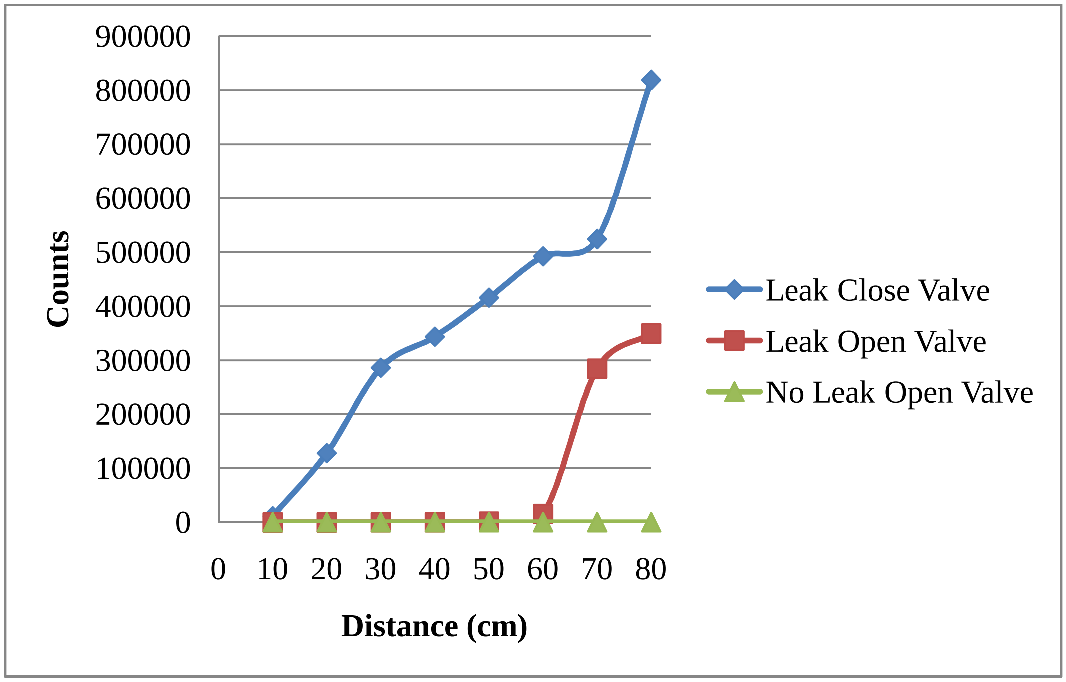

Figure 4.5: Counts against distance

From the above graft, it shows that the different of each type of pipe experiment in term of counts value. For pipe without leak and full open valve the value of counts are mostly zeros. This is because there are no AE activities in that pipe. For the pipe with leak and full close valve the value of counts are greater than the pipe with leak and full open valve. This is because during the pipe with leak and full close valve, the pressure of the pipe is increased and the speed of sound of the water come out from the leak is greater.

4.5.3 RMS

Figure 4.6 shows that the variation of RMS towards the distance of the leak. Basically, the pipe with leak and full close valve will produce higher RMS value than the pipe with leak and full open valve while the pipe without leak and full open valve will have the small value of RMS which is approximately zero.

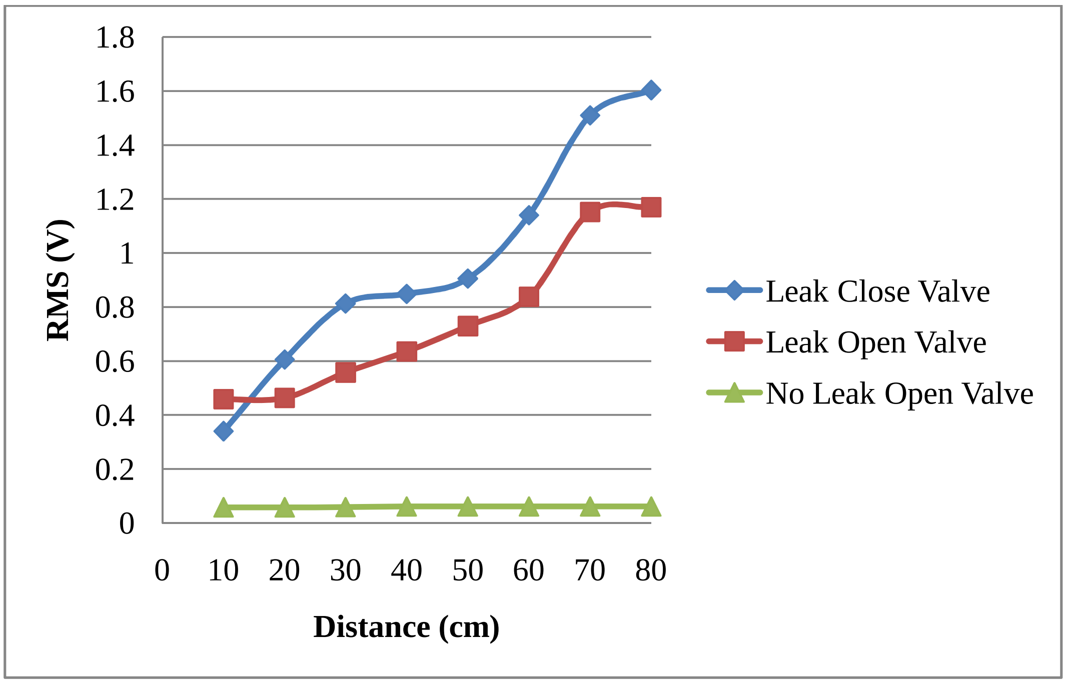

Figure 4.6: RMS against distance

From the above graft, it shows that the different of each type of pipe experiment in term of RMS parameter. For pipe without leak and full open valve the value of RMS are nearly zeros in range of 0.058 to 0.062 V. This is because there are no AE activities in that pipe. For the pipe with leak and full close valve the value of RMS are greater than the pipe with leak and full open valve. This is because during the pipe with leak and full close valve, the pressure of the pipe is increased and the speed of sound of the water come out from the leak is greater. Besides, the energy produces also greater.

4.6 DETERMINING THE LOCATION OF THE LEAK

One of the objectives of this experiment is to locate the source of the pipe leak using AE technique. From the data collected and analyzed, an equation can be produced to determine the point source of the leak. Figure 4.7 shows two equations produced from the RMS towards distance graft.

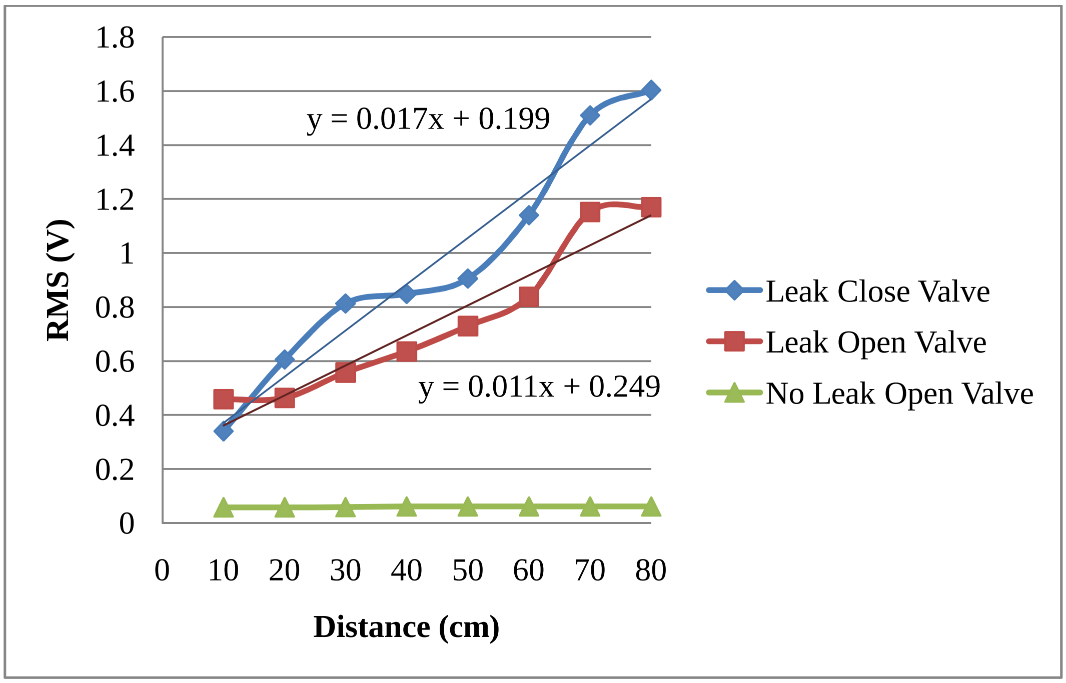

Figure 4.7: Equations for leak location

From the RMS against distance graft, a linear trend line was added to the plotted data before to show it correlation between the RMS value and the distance. From that, 2 equations were generated for the pipe with leak and full close valve and the pipe with leak and full open valve. For the pipe with leak and full close valve, the equation is: -

$$y = 0.017\,x + 0.199 \qquad (4.1)$$

For the pipe with leak and full open valve, the equation is: -

$$y = 0.011\,x + 0.249 \qquad (4.2)$$

Where y is the value of RMS and x is the value or position of the distance. From the both equations, for a value of RMS recorded by the sensor, the position of the leak, x can be calculated and determined. Take note that the equations are only valid for a pipe with the same or exactly the same diameter size with the diameter size of the pipe that had been used in the experiment. The distance that calculated is approximately near with the real leak on the inspected pipe.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

From this study, acoustic emission (AE) is a phenomenon of sound and ultrasound wave radiation in materials that undergo deformation and fracture processes. This study had proved that AE technique is a reliable and affordable system capable of monitoring pipe leak and locating the source of the leak. The technique offers great opportunity to have new approach of lower cost and time consuming for pipe monitoring.

From this project, AE signals were not found during the pipe without leak and full open valve. From the result gained, it proved that for the pipe without leak there will be no AE activities. Besides, it also shows that fluid and the pipe's wall can be the propagation medium for AE signals. For the pipe with leak, the near the sensor to the source of the leak the greater value of AE parameters were recorded. For the pipe with leak and full open valve, the results were slightly lower than the pipe with leak and full close valve.

Meanwhile, the introduction of two equations from the experiments can be the best indicator for locating the source of the pipe leak. The equations can be used in two conditions which are when the pipe with leak and full open valve and also when the pipe with leak and full close valve. However, the equations only valid for a pipe with the same or exactly the same diameter size with the diameter size of the pipe that had been used in the experiment. The distance that calculated is approximately near with the real leak on the inspected pipe. The equations can be shown in the Table 5.1.

Table 5.1: Equations for locating source of leak

PIPE CONDITION	EQUATION
Pipe with leak and full open valve	$y = 0.011\ x + 0.249$
Pipe with leak and full close valve	$y = 0.017\ x + 0.19$

Where *y* represents the RMS value and *x* is the distance of the leak.

5.2 RECOMMENDATIONS

The result for overall experiments was based on only eight points of interest for all pipe conditions. However, the result may be more accurate if more points of interest were used in the experiments. Besides, the data were gained within short period which was one minute. To get better result, the experiment must be performing within longer test period to gain more data.

More points for sensor can be done if the sensor itself has fit surface area with the pipe surface. Besides, the current sensor used has flat surface meanwhile the pipe is cylinder shape. The surface of the sensor does not fully touch the pipe and may cause inaccurate signals capturing. So, an adapter is needed to ensure all the sensor surface area can capture the AE signals from the pipe.

From previous studies, most of the researchers used two sensors for their experiments in locating the source of the pipe leak. One of the sensors for detecting signal generated by the micro leak whiles the other one as for signal referencing. They used a time difference technique which is based on the arrival time difference between the two sensors for known velocity. From there, the exact distance of the leak can be determined. As for the experiment done, the sensor applied only one so it is better if two sensors can be applied.

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APPENDIX A

Gantt chart for Final Year Project 1

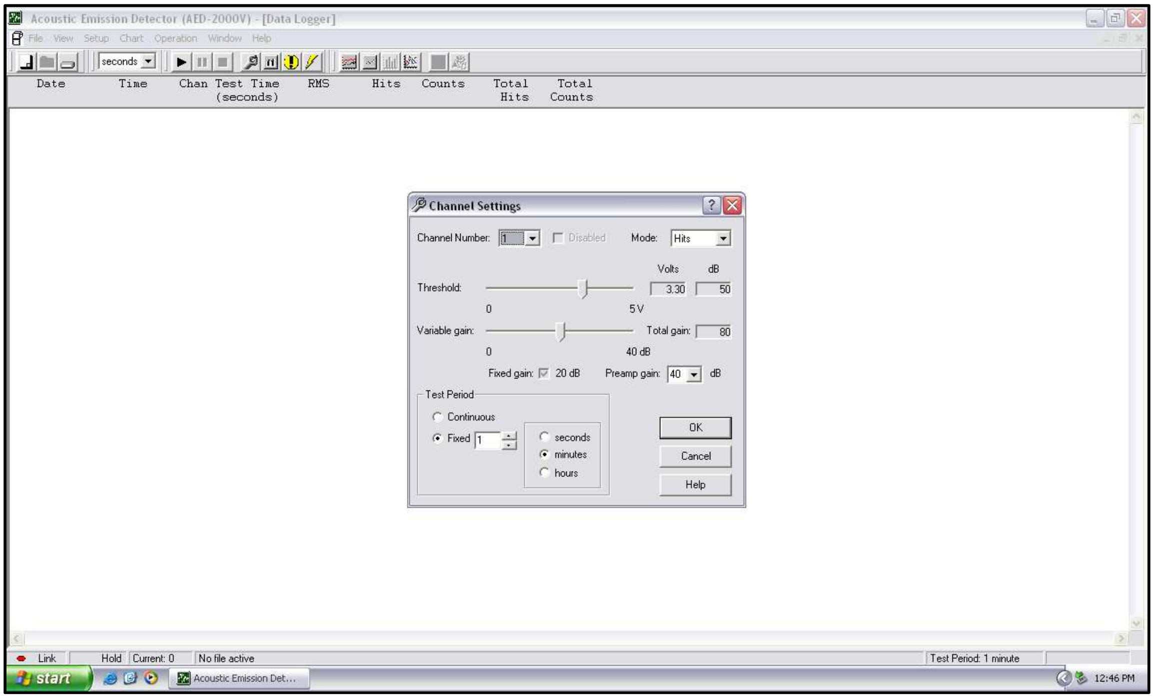
Project Progress		W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 14
1) Get the project title and arrange discussion time with supervisor	Planning	■													
	Actual	■													
2) Built the basic knowledge about the project (learning the theory)	Planning	■	■	■											
	Actual	■	■	■	■	■									
3) Do research and collect the information from various resources	Planning	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Actual	■	■	■	■	■	■	■	■	■	■	■	■	■	■
4) State the objective, scope and importance of the study (chapter I)	Planning			■	■	■									
	Actual			■	■	■									
5) Review study of acoustic emission journals and thesis (chapter II)	Planning					■	■								
	Actual					■	■	■							
6) Study of pipe crack monitoring and its component (chapter II)	Planning						■	■							
	Actual						■	■	■						
7) Study of acoustic emission technique and its applications (chapter II)	Planning							■	■						
	Actual							■	■	■					
8) Review of primary research on pipe crack monitoring (chapter II)	Planning								■	■					
	Actual								■	■	■				
9) Design the test rig and tools preparation (chapter III)	Planning										■	■			
	Actual											■	■		
10) State the overview of the experiment's procedures (chapter III)	Planning											■	■		
	Actual												■		
11) Provide the expected result based on previous research (chapter III)	Planning												■		
	Actual												■		
12) Submit draft thesis and log book for final year project 1	Planning													■	
	Actual													■	
13) Final year project 1 presentation	Planning														■
	Actual														■

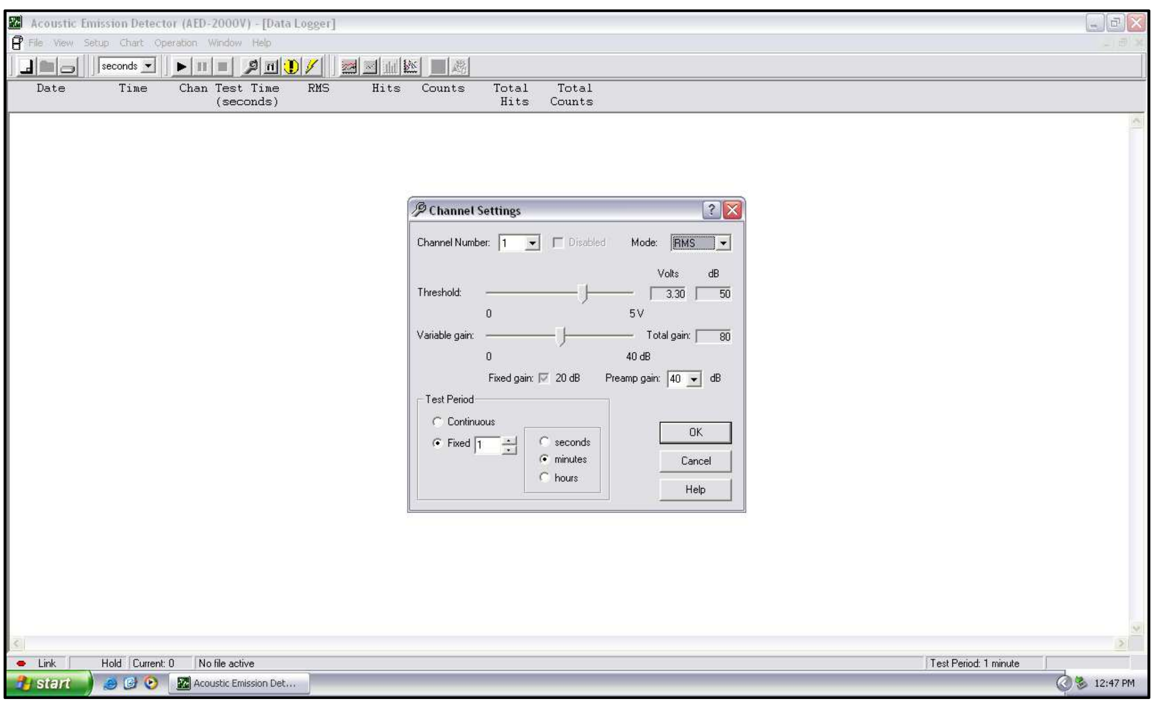
Gantt chart for Final Year Project 2

Project Progress		W 15	W 16	W 17	W 18	W 19	W 20	W 21	W 22	W 23	W 24	W 25	W 26	W 27	W 28	W 29	W 30
1) Tools preparation and test rig setup (built exact test rig)	Planning	■	■	■	■												
	Actual			■	■	■	■										
2) Perform acoustic leak detection experiment I (data collection)	Planning					■	■										
	Actual							■	■								
3) Perform experiment II to locate pipe leak (data collection)	Planning						■	■									
	Actual							■	■								
4) Experiment I's results analysis (calculation and discussion)	Planning							■	■								
	Actual								■	■							
5) Experiment II's results analysis (calculation and discussion)	Planning								■	■							
	Actual									■	■						
6) State initial summary based on experiments performed	Planning									■	■						
	Actual										■	■					
7) Discuss the analyzed results	Planning										■	■	■				
	Actual											■	■	■			
8) State the possible error during the experiment	Planning												■	■			
	Actual													■	■		
9) Make conclusion and provide suggestion for improvement	Planning												■	■			
	Actual													■	■		
10) Final year project 2 presentation	Planning														■		
	Actual														■		
11) Prepare the proper thesis to submit	Planning														■	■	■
	Actual														■	■	■

APPENDIX B

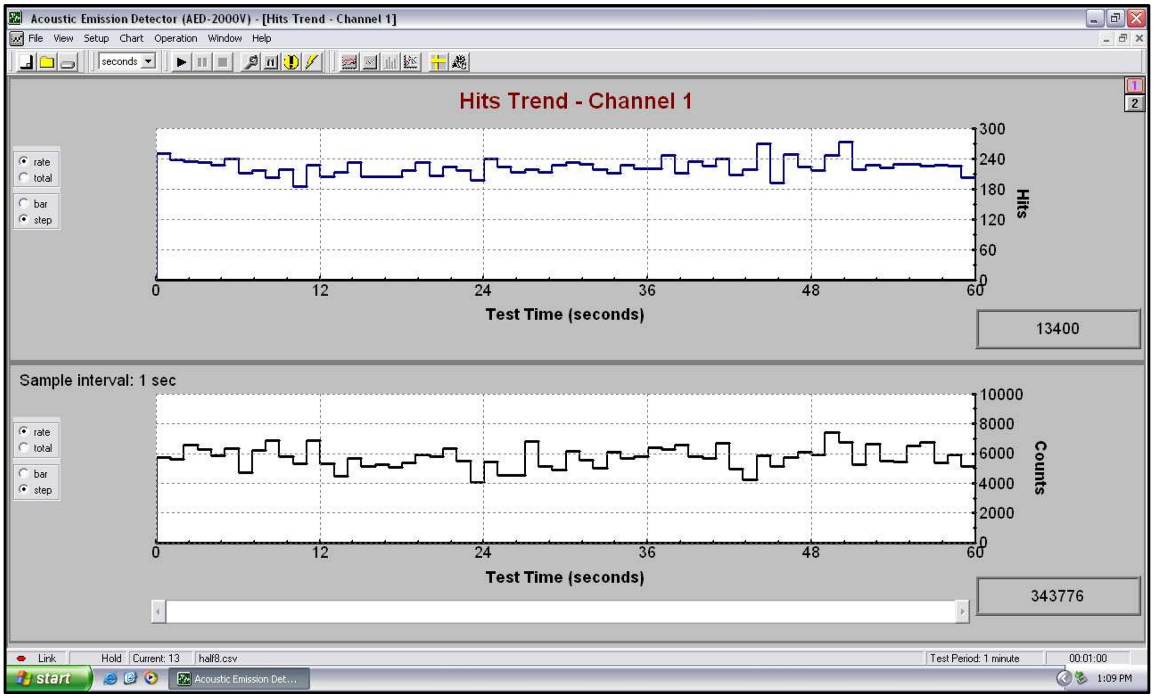
Mode setup applied for Acoustic Emission Detector 2.1.3 software.

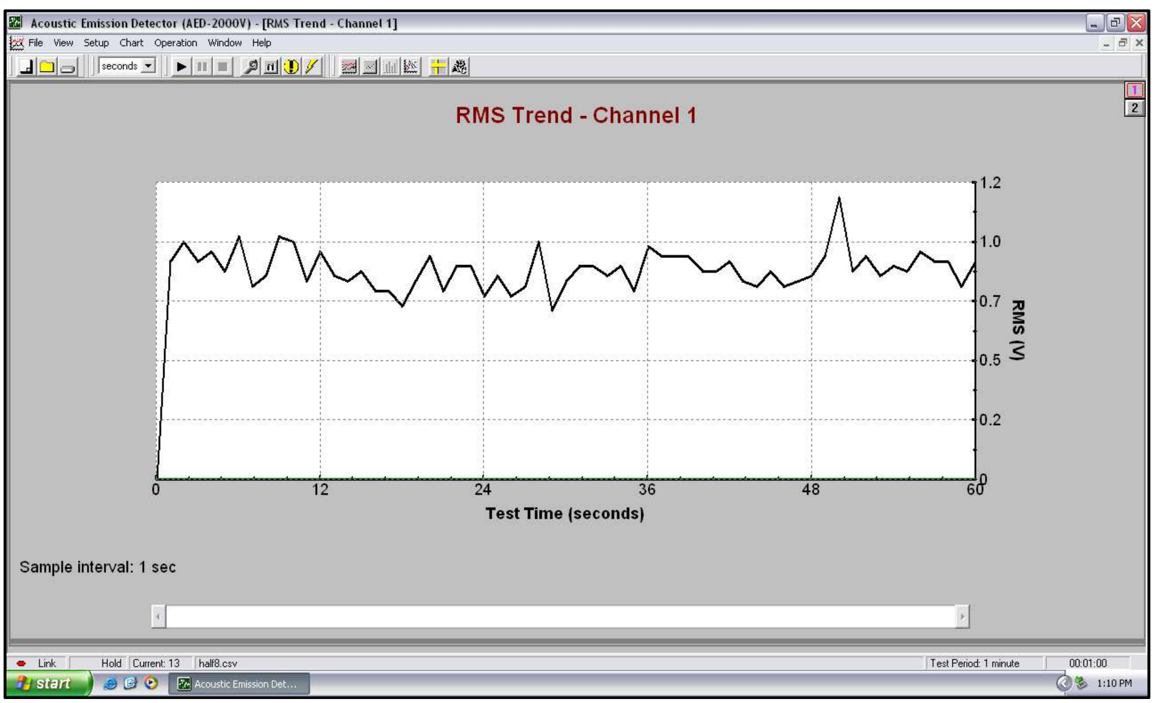


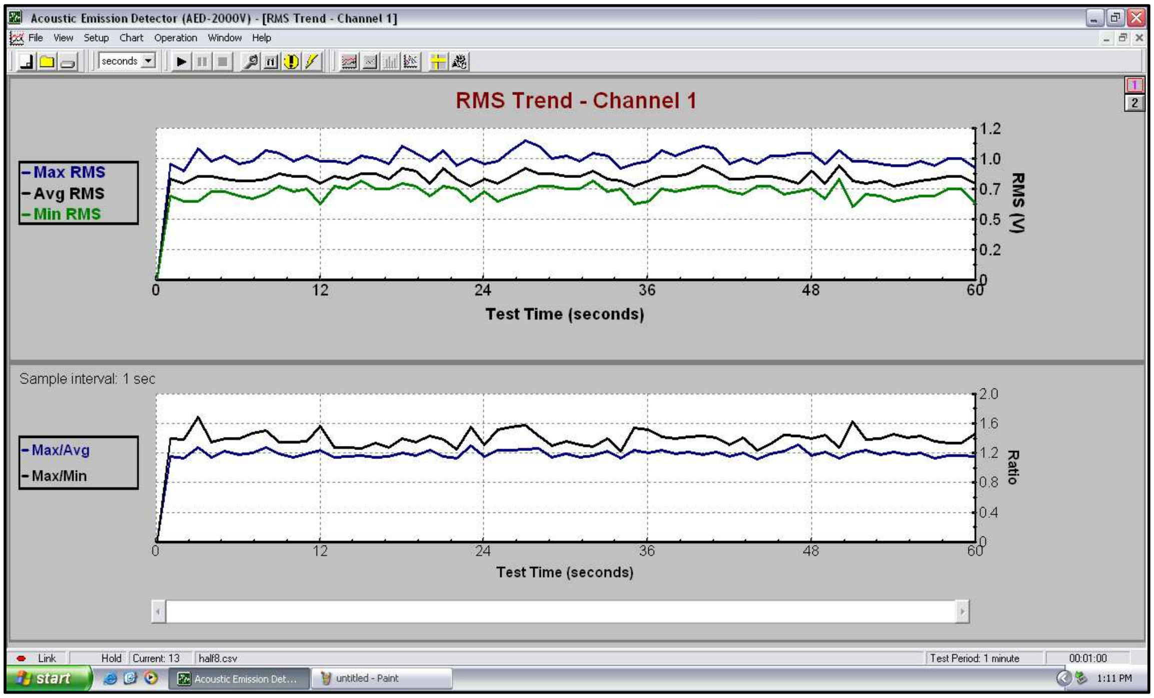


APPENDIX C

The example of AE signals that viewed using Acoustic Emission Detector 2.1.3 software.







Acoustic Emission Detector (AED-2000V) - [RMS Trend - Channel 1]
File View Setup Chart Operation Window Help
seconds
RMS Trend - Channel 1
Max RMS
Avg RMS
Min RMS
RMS (V)
1.2
1.0
0.7
0.5
0.2
0
0
12
24
36
48
60
Test Time (seconds)
Sample interval: 1 sec
Max/Avg
Max/Min
Ratio
2.0
1.6
1.2
0.8
0.4
0
0
12
24
36
48
60
Test Time (seconds)
Link
Hold
Current: 13
half8.csv
Test Period: 1 minute
00:01:00
start
Acoustic Emission Det...
untitled - Paint
1:11 PM

APPENDIX D

The example of the test data gained for every pipe conditions.

Test data: Pipe without leak and full open valve (Point 8)

Test Time	Hits mode			Counts mode		
	Hits	Counts	RMS	Avg. RMS	Min. RMS	Max. RMS
1	0	0	0.06	0.06	0.04	0.1
2	0	0	0.06	0.06	0.04	0.1
3	0	0	0.06	0.06	0.02	0.08
4	0	0	0.06	0.06	0.04	0.1
5	0	0	0.06	0.04	0.04	0.1
6	0	0	0.06	0.06	0.02	0.14
7	0	0	0.08	0.06	0.02	0.1
8	0	0	0.06	0.06	0.06	0.08
9	0	0	0.06	0.06	0.06	0.1
10	0	0	0.06	0.06	0.04	0.14
11	1	2	0.06	0.04	0.02	0.1
12	0	0	0.06	0.04	0.02	0.08
13	0	0	0.06	0.04	0.02	0.1
14	0	0	0.06	0.06	0.02	0.1
15	0	0	0.06	0.06	0.02	0.1
16	0	0	0.06	0.06	0.04	0.1
17	0	0	0.06	0.04	0.02	0.08
18	0	0	0.06	0.06	0.02	0.1
19	0	0	0.06	0.06	0.06	0.08
20	0	0	0.06	0.06	0.04	0.14
21	0	0	0.16	0.04	0.02	0.08
22	0	0	0.06	0.06	0.04	0.14
23	0	0	0.06	0.06	0.04	0.08
24	0	0	0.06	0.06	0.02	0.14
25	0	0	0.06	0.06	0.02	0.1
26	0	0	0.06	0.04	0.02	0.1
27	0	0	0.06	0.04	0.02	0.06
28	0	0	0.06	0.06	0.02	0.12
29	0	0	0.06	0.04	0.02	0.06
30	0	0	0.06	0.04	0.02	0.14
31	0	0	0.06	0.04	0.02	0.08
32	0	0	0.06	0.06	0.02	0.14

33	0	0	0.06	0.06	0.06	0.12
34	0	0	0.06	0.06	0.02	0.1
35	0	0	0.06	0.06	0.04	0.1
36	0	0	0.06	0.04	0.02	0.1
37	0	0	0.06	0.06	0.06	0.12
38	0	0	0.06	0.06	0.04	0.1
39	0	0	0.06	0.06	0.04	0.14
40	0	0	0.06	0.06	0.04	0.1
41	0	0	0.06	0.04	0.02	0.06
42	0	0	0.06	0.06	0.06	0.1
43	0	0	0.06	0.06	0.02	0.14
44	0	0	0.08	0.06	0.06	0.12
45	0	0	0.06	0.06	0.02	0.14
46	0	0	0.06	0.06	0.04	0.14
47	0	0	0.06	0.06	0.02	0.1
48	0	0	0.06	0.04	0.02	0.1
49	0	0	0.06	0.06	0.02	0.1
50	0	0	0.06	0.04	0.02	0.1
51	0	0	0.06	0.06	0.04	0.12
52	0	0	0.06	0.04	0.02	0.06
53	0	0	0.06	0.06	0.06	0.06
54	0	0	0.06	0.04	0.02	0.06
55	0	0	0.06	0.04	0.02	0.1
56	0	0	0.06	0.06	0.04	0.14
57	0	0	0.06	0.04	0.02	0.08
58	0	0	0.06	0.06	0.06	0.08
59	0	0	0.06	0.04	0.02	0.08
60	0	0	0.06	0.06	0.06	0.1

Test data: Pipe with leak and full open valve (Point 8)

Test Time	Hits mode			RMS mode		
	Hits	Counts	RMS	Avg. RMS	Min. RMS	Max.RMS
1	664	3558	1.06	1.32	1.26	1.4
2	524	23246	1.08	1.36	1.3	1.42
3	624	3237	1.14	1.3	1.26	1.42
4	626	7774	1.18	1.34	1.28	1.48
5	650	3472	1.06	1.36	1.26	1.42
6	653	3875	1.12	1.4	1.3	1.48
7	653	4073	1.16	1.32	1.26	1.4
8	654	3817	1.1	1.36	1.24	1.44
9	644	3578	1.06	1.36	1.28	1.44
10	647	3600	1.1	1.3	1.26	1.38
11	541	19568	1.36	1.28	1.2	1.4
12	593	11961	1.1	1.3	1.22	1.38
13	612	2965	1.08	1.28	1.2	1.38
14	618	3094	1.12	1.28	1.18	1.36
15	645	3441	1.08	1.24	1.16	1.32
16	650	3249	1.1	1.2	1.14	1.28
17	645	3339	1.12	1.2	1.14	1.3
18	576	12529	1.1	1.22	1.14	1.3
19	565	14655	1.4	1.22	1.18	1.28
20	614	9846	1.92	1.2	1.12	1.34
21	621	3262	1.12	1.22	1.18	1.3
22	638	3435	1.12	1.22	1.18	1.3
23	613	2782	1.04	1.24	1.18	1.34
24	555	1998	0.98	1.2	1.14	1.28
25	554	2273	1.02	1.22	1.18	1.26
26	613	2748	1.06	1.2	1.16	1.28
27	629	5512	1.24	1.2	1.18	1.28
28	648	4307	1.14	1.2	1.14	1.32
29	614	10834	1.92	1.22	1.18	1.3
30	646	4554	1.12	1.2	1.14	1.28
31	653	3179	1.12	1.24	1.18	1.32
32	633	5142	1.06	1.2	1.14	1.28
33	508	19254	2.12	1.2	1.14	1.28
34	639	6062	1.14	1.2	1.14	1.28
35	588	13654	1.14	1.2	1.14	1.26
36	659	3702	1.12	1.2	1.14	1.3
37	634	3901	1.18	1.26	1.2	1.32

38	635	3405	1.12	1.24	1.16	1.32
39	652	3603	1.1	1.26	1.2	1.42
40	657	3911	1.12	1.24	1.2	1.36
41	649	4645	1.16	1.26	1.2	1.38
42	642	3817	1.06	1.18	1.14	1.26
43	593	5442	1.08	1.22	1.18	1.3
44	592	2845	1.06	1.18	1.12	1.26
45	601	2425	1.1	1.2	1.18	1.28
46	522	11248	1.88	1.2	1.14	1.3
47	574	2115	1.04	1.24	1.16	1.3
48	551	2043	1.06	1.22	1.16	1.3
49	592	2211	1.06	1.2	1.18	1.24
50	590	2548	1.1	1.2	1.18	1.28
51	572	2204	1.02	1.18	1.12	1.24
52	557	2265	1.02	1.24	1.16	1.38
53	482	14336	1	1.12	1.08	1.2
54	617	2678	1.04	1.14	1.1	1.22
55	612	2958	1.1	1.24	1.2	1.3
56	633	3933	1.16	1.18	1.1	1.26
57	580	11101	1.16	1.12	1.04	1.22
58	592	4009	1.1	1.14	1.04	1.22
59	636	5062	1.14	1.14	1	1.24
60	601	9190	1.42	1.08	0.94	1.22

Test data: Pipe with leak and full close valve (Point 8)

Test Time	Hits mode			RMS mode		
	Hits	Counts	RMS	Avg. RMS	Min. RMS	Max. RMS
1	532	15918	1.54	1.64	1.44	1.8
2	495	15810	1.44	1.54	1.42	1.74
3	500	12877	1.58	1.68	1.54	1.86
4	488	15146	1.56	1.66	1.48	1.8
5	489	12731	1.52	1.62	1.5	1.82
6	474	14033	1.52	1.62	1.46	1.72
7	499	13866	1.68	1.64	1.5	1.78
8	494	13644	1.54	1.6	1.34	1.74
9	501	13349	1.56	1.6	1.48	1.76
10	494	12478	1.5	1.62	1.5	1.78
11	466	12356	1.6	1.58	1.42	1.74
12	482	14671	1.68	1.62	1.5	1.8
13	499	14295	1.56	1.64	1.52	1.82
14	494	13234	1.68	1.66	1.5	1.84
15	480	14341	1.62	1.64	1.46	1.88
16	521	12717	1.62	1.64	1.54	1.74
17	488	15850	1.6	1.6	1.44	1.76
18	489	13429	1.58	1.62	1.5	1.74
19	509	13752	1.7	1.6	1.46	1.74
20	503	13333	1.64	1.48	1.34	1.66
21	459	15410	1.68	1.62	1.54	1.74
22	495	13741	1.6	1.6	1.44	1.76
23	505	13382	1.58	1.64	1.52	1.76
24	500	13802	1.54	1.64	1.5	1.8
25	512	13523	1.6	1.62	1.46	1.78
26	491	12837	1.56	1.64	1.48	1.78
27	514	13938	1.64	1.62	1.5	1.82
28	511	14659	1.66	1.58	1.5	1.74
29	502	16531	1.64	1.62	1.48	1.82
30	500	15467	1.68	1.62	1.44	1.76
31	505	13670	1.64	1.64	1.48	1.78
32	453	14108	1.56	1.6	1.48	1.74
33	503	12000	1.7	1.56	1.44	1.72
34	478	12324	1.7	1.58	1.44	1.74
35	514	13434	1.62	1.62	1.42	1.8
36	491	12103	1.6	1.6	1.28	1.78
37	461	13497	1.62	1.62	1.48	1.78

38	491	14022	1.62	1.56	1.42	1.72
39	446	11728	1.62	1.6	1.44	1.76
40	516	14280	1.58	1.62	1.52	1.76
41	500	14559	1.52	1.6	1.4	1.78
42	473	12641	1.54	1.58	1.44	1.72
43	516	14669	1.62	1.66	1.56	1.8
44	524	14614	1.72	1.66	1.5	1.8
45	487	12362	1.68	1.62	1.44	1.8
46	469	12917	1.52	1.64	1.52	1.8
47	498	14658	1.6	1.58	1.44	1.7
48	476	13004	1.6	1.56	1.4	1.76
49	468	10646	1.62	1.62	1.46	1.76
50	512	13924	1.72	1.62	1.54	1.76
51	480	11814	1.62	1.62	1.54	1.74
52	498	14487	1.46	1.64	1.5	1.74
53	469	13974	1.6	1.62	1.5	1.76
54	491	13056	1.54	1.66	1.54	1.78
55	491	14429	1.68	1.62	1.42	1.78
56	488	13606	1.58	1.64	1.52	1.76
57	448	12784	1.74	1.58	1.42	1.7
58	503	12892	1.7	1.66	1.5	1.8
59	477	13566	1.64	1.6	1.46	1.8
60	472	11782	1.34	1.62	1.52	1.72