ANALYSIS OF STRUCTURE BORNE WAVE SIGNATURES IN PIPELINE LEAKAGE DETECTION

SOH YAN XIN

BACHELOR ENGINEERING MECHANICAL
UNIVERSITY MALAYSIA PAHANG

ANALYSIS OF STRUCTURE BORNE WAVE SIGNATURES IN PIPELINE LEAKAGE DETECTION

SOH YAN XIN

Report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2013

UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled “Analysis of Structure Borne Wave Signatures in Pipeline Leakage Detection” is written by Soh Yan Xin. I have examined the final copy of this project and in my opinion; it is fully adequate in terms language standard, and report formatting requirement for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

Examiner **Signature**

SUPERVISOR’S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature : ....
Name of Supervisor : Mr. MOHD FADHLAN BIN MOHD YUSOF
Position : LECTURER
Date : ....

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature : ……………………………
Name : SOH YAN XIN
ID Number : MA10127
Date : ……………………………

Specially dedicated to
My beloved family and those who have guided and inspired me
Throughout my journey of learning

ACKNOWLEDGEMENTS

First, I would like to express my greatest gratitude to my supervisor- Mr Mohd Fadhlan bin Mohd Yusof who has given me help and guidance in completion of this thesis. I am grateful for his tolerance of my naive mistakes, and his commitment to my future career.

My sincere thanks go to the Mechanical Engineering Department, UMP, who helped me in many ways and made my stay at UMP pleasant and unforgettable. Many special thanks go to the vibration lecture and the staff of the vibration lab that co-operation, inspirations and supports during my experiments progress.

My gratitude also goes to my family for their love, dream and sacrifice throughout my life and encouraged me to carry on my higher studies in Malaysia. I also would like to thanks to my beloved friends for sharing their information, giving moral support when the progress in the experiments. Lastly, I would like to thanks again to all people who help me when the final year project period.

ABSTRACT

The present work is aimed to detect gas leakage on the analysis of structure borne wave. Through acoustic emission, the structure borne wave generated by gas leakage in pipeline could be detected and analysed while in operation.

The experiments were carried out using a test rig designed in such a way where three kinds of leakages usually happening in the industries can be imitated and done in the laboratory. The experiments were done on detecting acoustic emission on three different small defects which were thread leakage, pinhole leakage and gasket leakage.

It was found experimentally that the slightest leakage would cause acoustic emission to be detected. The detected acoustic emission would increase following the size of the leakage even when the test rig is in operation.

In conclusion, acoustic emission is able to detect small leakages of different types. This particular technique can be utilized for greater use in the industry to detect leakage during operation of pipeline.

ABSTRAK

Kajian ini bertujuan untuk mengesan kebocoran gas dengan analisis gelombang struktur bawaan. Melalui pacaran akustik, gelombang struktur bawaan yang dijana oleh kebocoran gas dalam saluran paip boleh dikesan dan dianalisa semasa operasi.

Experimen dilakukan pada saluran paip yang dibina khas supaya tiga jenis kebocoran yang selalunya berlaku dalam industry dapat dilakukan di dalam makmal. Experimen telah dijalankan untuk mengesan pancaran akustik pada tiga kebocoran yang sangat kecil, termasuklah kebocoran thread, kobocoran pinhole dan kebocoran gasket.

Melalui experimen, telah dikesan bahawa kebocoran yang kecil akan menyebabkan pancaran akustik dikesan. Pancaran akustik yang dikesan akan bertambah mengikut size kebocoran walau semasa paip itu masih dalam operasi.

Secara konklusi, pancaran akustik dapat mengesan pelbagai kebocoran kecial. Teknik ini boleh digunakan untuk mengesan kebocoran paip in industry.

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

CHAPTER 2 LITERATURE REVIEW

CHAPTER 3 RESEARCH METHODOLOGY

CHAPTER 4 RESULT AND DISCUSSION

4.1 Result

4.2 Principal Component Analysis (PCA) Result

4.2.1 PCA Result for Speed of 440 RPM

4.2.2 PCA Result for Speed of 1480 RPM

4.2.3 PCA Result for Speed of 2672 RPM

4.3 Agglomerative Hierarchical Clustering

4.3.1 Dendrogram Speed of 440 RPM

4.3.2 Dendrogram Speed of 1480 RPM

4.3.3 Dendrogram Speed of 2672 RPM

LIST OF TABLES

Table No.

LIST OF FIGURES

Figure No.

LIST OF SYMBOLS

σ	Stress
r	Radius
p	Pressure
$\sigma\ allowable$	Allowable Stress
$\sigma\ yield\ stress$	Yield Stress
SF	Safety Factor

LIST OF ABBREVIATIONS

SCC	Stress Corrosion Cracking
NDT	Nondestructive Testing
AE	Acoustic Emission
AET	Acoustic Emission Testing
ASME	American Society of Mechanical Engineer

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Pipeline networks are the most economic and safest pipeline transport for mineral oil, gases and other fluid products. As a means of long-distance transport, pipelines have to fulfill high demands of safety, reliability and efficiency. The market size for oil and gas pipeline construction experienced tremendous growth prior to the economic downturn in 2008. The industry grew from $23 billion in 2006 to $39 billion in 2008 (Mo, 2003).

Oil pipelines are made from steel or plastic tubes with inner diameter typically from 2 to 48 inches (50 to 1,200 mm). Most pipelines are typically buried at a depth of about 3 to 6 feet (0.91 to 1.8 m). To protect pipes from impact, abrasion, and corrosion, a variety of methods are used. These can include wood lagging (wood slats), concrete coating, rockshield, high-density polyethylene, imported sand padding, and padding machines, (Mo, 2003). Once the protections are not done properly, leakage would occur, leading to the happening of accidents. The accidents not only lead to the loss of property but also human life, (Mo, 2003).

Accurate leak detection, enabling a quick response, is necessary to minimize damage. Leak detection methods previously proposed are reflected wave or timing methods (Brunone, 1999) volume balance methods (Griebenow and Mears, 1989) pressure or flow deviation methods (Griebenow and Mears 1989) acoustic methods (Fuchs and Riehle 1991) pig-based monitoring and on-line surveillance methods (Black 1992) frequency analysis methods (Jönsson and Larson 1992) inverse techniques

(Pudar and Liggett 1992) and a genetic algorithm method (Vı´tkovsky´ et al, 2000). However, no single method can always meet operational needs from an accurate and cost point of view (Furness and Reet 1998). Each of these leak detection techniques has its advantages and disadvantages in different circumstances.

1.2 PROBLEM STATEMENT

Leakage from pipelines has the potential to cause significant environmental damage and economic loss. While pipelines are designed and constructed to maintain their integrity, it is difficult to avoid the occurrence of leakage in a pipeline system during its lifetime (Hovey and Farmer 1999). According to the Pipeline and Hazardous Materials Safety Administration's statistics, pipeline accidents kill or hospitalize at least one person in the U.S. every 6.9 days on average, and cause more than $272 million in property damage per year in the United States. 45% of the cases are caused by pipeline leakages, indicating the importance of pipeline leakage detection.

Scientific workers and engineers investigated and developed several technologies such as gas detection, detection of sound for pipeline leakage detection. Unfortunately all current methods can not meet the minimum requirement of industrial users. Most of them don't have enough sensitivity to detect at least applicable amount of leakage even sometimes do well for above pipeline leakage detection, (Liu, 2001). Another example of method based on the leakage is sound detection in the air. Theoretically the sound is generated together with leakage and is spread in the air to be detected. But after transmitting through the crust soil the sound become very weak and is difficult to be detected, (Jun, 1997). Generally, non-destruction techniques that are used includes, visual and optical testing, radiography, magnetic particle testing, ultrasonic testing, penetrant testing, electromagnetic testing, leak testing and acoustic emission testing, (Catlin, 1983). Acoustic Emission Technique is unlike most other non-destructive testing (NDT) techniques. Instead of supplying energy to the object under examination, AET simply listens for the structure borne wave 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. Besides that, AE could detect very little defect. This is required as most pipeline leakages start from very minor defects before leading to massive leakage, (James, 2003). The function of AE being able to detect very little defect during operation of structure further indicating the importance of the research.

1.3 OBJECTIVE

The main objective of the study is to detect gas leakage on the analysis of structure borne wave. Through acoustic emission, the structure borne wave generated by gas leakage in pipeline could be detected and analysed while in operation.

1.4 SCOPE

I. Design and fabrication of test rig for a pressure of 4 bars.
II. The types of leakages that will be tested are pinhole, crack and gasket leakage.
III. The type of phenomenon examined in the research would be acoustic emission.

CHAPTER 2

LITERATURE REVIEW

2.1 Pipeline Accident and Damage Statistic

Pipeline network is used throughout the world due to its efficiency. Due to the fact that most pipeline network is planted down in earth, one of the biggest problems facing the pipeline industry is the fact that the world’s pipeline infrastructure is ageing. Over 50% of the 1,000,000km USA oil and gas pipeline system is 40 years old. These old pipeline would lead to leakage and then accidents would happen.

Accidents due to leakage happened in countries like Belgium, China, Mexico, Kenya, Nigeria and Russia after these countries used pipeline network widely in the 21st century, (Dranken, 2005).

Table 2.1: Hazardous Liquid Pipeline Accident Summary by Cause
1/1/2002 - 12/31/2003 in the USA.

Reported Cause	**Number of Accidents**	**% of Total Accidents**	**Barrels Lost**	**Property Damages**	**% of Total Damages**	**Fatalities**	**Injuries**
Excavation	40	14.7	35,075	$8,987,722	12.0	0	0
Natural Forces	13	4.8	5,045	$2,646,447	3.5	0	0
Other Outside Force	12	4.4	3,068	$2,062,535	2.8	0	0
Materials or Weld Failure	45	16.5	42,606	$30,681,741	41.0	0	0
Equipment Failure	42	15.4	5,717	$2,761,068	3.7	0	0
Corrosion	69	25.4	55,610	$17,775,629	23.8	0	0
Operations	14	5.1	8,332	$817,208	1.1	0	4
Other	37	13.6	20,022	$9,059,811	12.1	1	1
Total	272		175,475	$74,792,161		1	5

Source: The U. S. Department of Transportation's Research and Special Programs Administration, Office of Pipeline Safety 2003

Table 2.1 shows a table of hazardous liquid pipeline accident summary by cause back in the year 2002-2003. The number of accident in this particular country has reached 272 in two years, totalling a property lost of $74,792,161.

Table 2.2: Natural Gas Transmission Pipeline Incident Summary by Cause 1/1/2002 - 12/31/2003 in the USA.

Reported Cause	**Number of Incidents**	**% of Total Incidents**	**Property Damages**	**% of Total Damages**	**Fatalities**	**Injuries**
Excavation Damage	32	17.8	$4,583,379	6.9	2	3
Natural Force Damage	12	6.7	$8,278,011	12.5	0	0
Other Outside Force Damage	16	8.9	$4,688,717	7.1	0	3
Corrosion	46	25.6	$24,273,051	36.6	0	0
Equipment	12	6.7	$5,337,364	8.0	0	5
Materials	36	20.0	$12,130,558	18.3	0	0
Operation	6	3.3	$2,286,455	3.4	0	2
Other	20	11.1	$4,773,647	7.2	0	0
Total	180		$66,351,182		2	13

Source: The U. S. Department of Transportation’s Research and Special Programs Administration, Office of Pipeline Safety, 2003

Table 2.2 shows the natural gas transmission pipeline incident summary by cause in the year 2002 and 2003. A total of 180 cases have occurred and a total of $66,351,182 property damage has occurred.

Table 2.3: Natural Gas Distribution Pipeline Incident Summary by Cause 1/1/2002 - 12/31/2003 in the USA.

Reported Cause	**Number of Incidents**	**% of Total Incidents**	**Property Damages**	**% of Total Damages**	**Fatalities**	**Injuries**
Construction/Operation	20	8.1	$3,086,000	6.7	0	16
Corrosion	3	1.2	$60,000	0.1	2	9
Outside Force	153	62.2	$32,334,352	70.1	6	48
Other	70	28.5	$10,617,683	23.0	13	31
Total	246		$46,098,035		21	104

Source: The U. S. Department of Transportation's Research and Special Programs Administration, Office of Pipeline Safety, 2003

Table 2.3 shows the natural gas distribution pipeline incident summary by cause in the year 2002-2003. A Total of 246 accidents have happened and a total of

$46,098,035 property damage has occurred. These sums up to a total of 698 accidents and $120,241,378 lost. 53% of the accidents are caused by leakage. The leakages caused by defects.

2.1.1 Corrosion

According to table 2.1, 2.2 and 2.3, corrosion is the main reason of leakage with 25.4% in liquid pipeline accident, 25.6% in natural gas transmission pipeline incident and 1.2% of natural gas distribution pipeline. Corrosion is the breakdown of the parent material due primarily to electrochemical methods where there is an exchange of electrons between two materials. This means electrochemical oxidation of metals in reaction with an oxidant such as oxygen Corrosion has the potential to reduce a product's design life by premature degradation. The rates of attack and severity of corrosion will vary depending on the influencing factors mentioned above. The type of corrosion that is experienced may vary as well (Mattson, 1996). Typical corrosion types found on pipelines include, uniform or general corrosion, it proceeds at approximately the same rate over the whole surface being corroded and the extent can be measured as mass loss per unit area. Pitting corrosion, it results in pits in the metal surface due to localized corrosion. Crevice corrosion, it occurs in or immediately around a break in the material. Intergranular corrosion, it results in corrosion at or near the grain boundaries of the metal. Erosion Corrosion, it involves conjoint erosion and corrosion that typically occurs in fast flowing liquids that have a high level of turbulence. Environment-induced cracking, it results from the joint action of mechanical stresses and corrosion. Stress Corrosion Cracking (SCC) falls within this group.

Figure 2.1: An example of general deep pitting corrosion with some pits joining to form larger pits and interconnected pitting.

Source: Ginzel, 2003

Figure 2.2: the pitting corrosion on the back of the pipe and in the background.

Source: Ginzel, 2003

Figure 2.1 and 2.2 shows different stages of pitting corrosion happening to pipeline. Pitting corrosion is a localized form of corrosion by which cavities or "holes" are produced in the material. Pitting is considered to be more dangerous than uniform corrosion damage because it is more difficult to detect, predict and design against, (Roberts, 1998). Corrosion products often cover the pits. A small, narrow pit with minimal overall metal loss can lead to the failure of an entire engineering system. Pitting corrosion, which, for example, is almost a common denominator of all types of localized corrosion attack.

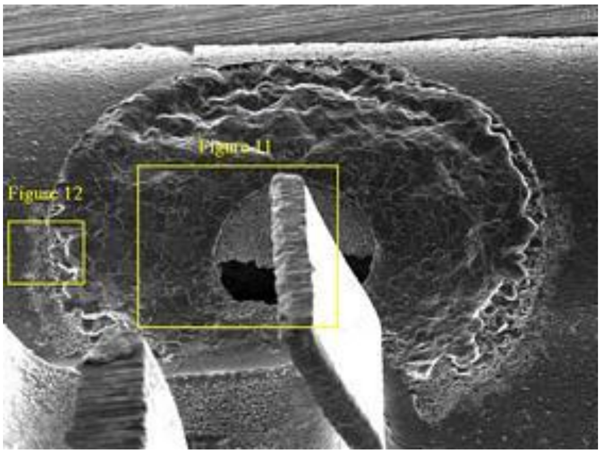


Figure 2.3: Pinhole leakage with corrosion pit

Source: Ginzel, 2003

Figure 2.3 shows pinhole leaks results from pitting corrosion. Leaks from this corrosion can cause drywall damage, leaks on floors, mold build-up. It is hard to predict and the mechanisms are difficult to sort out, (Darren Lytle, 2003).

2.1.2 Thread Leakage

A lot of types of screw threads have evolved for fastening, and hydraulic systems. In nineteenth century, different types of screw threads were required for hydraulic and pneumatic circuits as well as fastening systems. This resulted in compatibility problem. Sir Joseph Whitworth, the English mechanical engineer and inventor devised a uniform threading system in 1841 to address the incompatibility problem.

Despite the standards created to maintain uniform fittings, tapered pipe threads are inexact and during the course of use and repair the threads can become damaged and susceptible to leakage. The area where the crest and the root of the thread meet can form a spiral leak path no amount of tightening will eliminate.

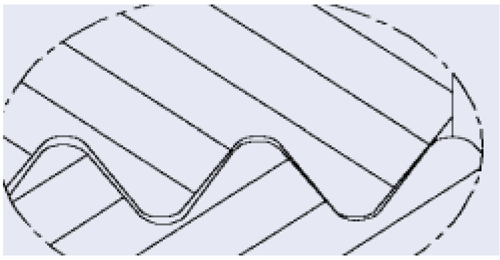


Figure 2.4: Situation when thread does not fit

Source: Ginzel, 2003

Figure 2.4 shows Situation where thread does not fit, leading to leakage. The most common way of preventing thread leakage is through using Teflon tape wrapped 2 to 3 turns around the male thread before assembly. Liquid Teflon based sealants are also used to ensure a pressure tight seal. Nevertheless, the leakage prevention is not totally secure and leakage can still happen, showing the need for leakage detection.

2.1.3 Gasket Leaking

Gasket leaking is usually very small and hard to detect, (Eiber, 1984). In many joints the bolt spacing is dictated by the gasket pressure mid-way between bolts. If insufficient pressure is applied to the gasket in such regions, leakage can result.

Local crushing of the gasket can occur if the clamp force generated by the bolt is excessive for a particular gasket material. Special pressure sensitive film (such as Fuji film) can be used, once the joint is designed, to determine what the local pressures are within a joint. All gaskets have a crush strength which, if exceeded, will result in excessive creep leading to leakage. With such a small thickness, the leakage due to gasket is hard to detect by other means other than acoustic emission, (Eiber, 1984).

Pinhole leaks, cracks, corrosion and leaking gaskets tend to occur first in pipeline (Eiber, 1984). The research on these few leakages would be significant to provide a solution to reduce the accidents that are happening due to leakage of pipeline networks.

2.2 Theory of Sound Wave

Sound is a mechanical wave that is an oscillation of pressure transmitted through a solid, liquid, or gas composed of frequency within the range of hearing, (Houghton, 2008)

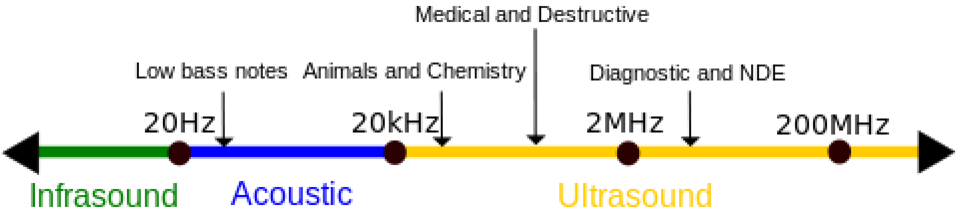


Figure 2.5: Frequency ranges of all sound

Source: **NDT Education Resource Center**

Developed by the Collaboration for NDT Education

Figure 2.5 shows the frequency range of sound. Ultrasound is a cyclic sound pressure wave with a frequency greater than the upper limit of the human hearing range. Ultrasound is thus not separated from audible sound based on differences in physical properties, only the fact that humans cannot hear it. Although this limit varies from person to person, it is approximately 20 kilohertz (20,000 hertz) in healthy, young adults. Ultrasound devices operate with frequencies from 20 kHz up to several gigahertz. Infrasound, sometimes referred to as low-frequency sound, is sound that is lower in frequency than 20 Hz (Hertz) or cycles per second, the normal limit of human hearing. Hearing becomes gradually less sensitive as frequency decreases, so for humans to perceive infrasound, the sound pressure must be sufficiently high. The ear is the primary organ for sensing infrasound, but at higher levels it is possible to feel infrasound vibrations in various parts of the body, (Geirland, 2006).

For most acoustic sources, the sound emission is a consequence of complex internal mechanisms which force machine parts to vibrate which then radiate into the ambient air (airborne sound), or pass vibrations through liquid-filled systems such as pipes (fluid-borne sound), or re-excite connected and supporting structures (structure-borne sound). The present work is devoted to the last case of emission, the structural acoustic transmission.

Acoustic emission is widely used to detect leakage in industries. It can be used to detect leakage and monitor check valves in nuclear power plant, (Lee, 2006). It is also used to do leak detection to process recovery boilers, (Kovecevich, 1995). Besides that, it can also be used to detect undergraound pipeline leakage, (Liu, 2003). It is also used to detect slow growth of cracks on bridges, (Hamstad, 2003). It is also seen that acoustic emission is used in real-time leakage test and location in tank bottoms, (Bolt, 1997).

2.3 Non destructive testing for leak detection

Nondestructive testing (NDT) is test methods used to examine an object, material or system without impairing its future usefulness, (Bruce, 1997). Because NDT does not permanently alter the article being inspected, it is a highly valuable technique that can save both money and time in product evaluation, troubleshooting, and research.

NDT are used for different purposes, including flaw detection and evaluation, leak detection, location determination, dimensional measurements, structure and microstructure characterization, estimation of mechanical and physical properties, stress (strain) and dynamic response measurements, (Hawman, 1988).

There are different NDT used to detect leakages in pipeline. The most common ones include radiography, eddy current testing, ultrasound and acoustic emission.

Eddy current testing is particularly well suited for detecting surface cracks but can also be used to make electrical conductivity and coating thickness measurements, (Nigel, 1989). A small surface probe is canned over the part surface in an attempt to detect a crack. It is usually used to detect surface and near- surface flaws in conductive materials, such as metals. Eddy current inspection is also used to sort materials based on electrical conductivity and magnetic permeability, and measures the thickness of thin sheets of metal and nonconductive coatings such as paint, (Nigel, 1989). The main advantages are it detects surface and near surface defects. Test probe does not need to contact the part. The method can be used for more than flaw detection and minimum part preparation is required. The disadvantages are, only conductive materials can be inspected. Ferromagnetic materials require special treatment to address magnetic permeability. Depth of penetration is limited. Flaws that lie parallel to the inspection probe coil winding direction can go undetected. Skill and training required is more extensive than other techniques. Surface finish and roughness may interfere. Reference standards are needed for setup.

For ultrasonic imaging, high resolution images can be produced by plotting signal strength or time-of-flight using a computer-controlled scanning system, (Varian, 1980). It is used to locate subsurface defects in many materials including metals, plastics, and wood. Ultrasonic inspection is also used to measure the thickness of materials and otherwise characterize properties of material based on sound velocity and attenuation measurements, (Varian, 1980). The main advantages are the depth of penetration for flaw detection or measurement is superior to other methods. Only single sided access is required. It provides distance information. Minimum part preparation is required. Method can be used for much more than just flaw detection. The main disadvantages are, surfaces must be accessible to probe and couplant. Skill and training required is more extensive than other technique. Surface finish and roughness can interfere with inspection. Thin parts may be difficult to inspect. Linear defects oriented parallel to the sound beam can go undetected. Reference standards are often needed.

The spark coil technique uses a high voltage or Tesla cod and sparkling point to create the electromagnetic radiation which causes the generation of glow discharge in neighbouring evacuated ampoules, (Kansky, 1983). Normally it is possible only in non metal envelopes, that means first of all in glass and plastic elements or tubing. Drawing the leak antenna along the tested element we can see plasma inside and coming to the leak, a sharp arc passage between plasma and antenna appears. The defect spot is very clearly marked and a skilled person can from the colour of plasma also estimate the inner pressure. This simple metod however has a number drawbacks; since besides the restricted application it is also to be avoided because of radiodisturbances.

Pressure change method uses pressure gauges which are ordinary used to monitor the system performance, (Beavis, 1970). Suspected leak sites can be squirted with a solvent while watching the gauge for a pressure rise that occurs when the solvent enters the leak. This method has limited sensitivity (depending also on the type of pressure measurement cell) and some shortcomings (possibility of solvent freezing causes temporary stuffing of leak, solvents may attack vacuum grease and elastomer gaskets).

Dye penetrant method is an adaptation of a technique used to find cracks in metals and defects in welds, (Wuts, 1982). It uses a low viscosity fluid that exhibits a high rate of surface migration. This fluid is painted on one side of a suspected leak site, and after a time, it is detected on the other side of the wall. The test is simple, low cost, it leaves records, the sensitivity can be as high as 10-6 mbarl/s

2.4 Acoustic Emission

Acoustic emissions (AE) are defined as transient elastic waves generated from a rapid release of strain energy caused by a deformation or damage within or on the surface of a material (Yoshioka, 1984).

The three major applications of AE techniques are source location , material mechanical performance and health monitoring, (Yoshioka, 1984). With the right equipment and setup, motions on the order of picometers (10 -12 m) can be identified. Sources of AE vary from natural events like earthquakes and rockbursts to the initiation and growth of cracks, slip and dislocation movements, melting, twinning, and phase transformations in metals. In composites, matrix cracking and fiber breakage and debonding contribute to acoustic emissions. AE's have also been measured and recorded in polymers, wood, and concrete, among other materials.

Detection and analysis of AE signals can supply valuable information regarding the origin and importance of a discontinuity in a material. Because of the versatility of Acoustic Emission Testing (AET), it has many industrial applications (e.g. assessing structural integrity, detecting flaws, testing for leaks, or monitoring weld quality) and is used extensively as a research tool.

Acoustic Emission is unlike most other nondestructive 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, AET 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, (Hawman, M. W, 1988).

The second difference is that AET deals with dynamic processes, or changes, in a material. This is particularly meaningful because only active features (e.g. 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 testing usually provides an immediate indication relating to the strength or risk of failure of a component. Other advantages of AET include fast and complete volumetric inspection using multiple sensors, permanent sensor mounting for process control, and no need to disassemble and clean a specimen.

Unfortunately, AE systems can only qualitatively gauge how much damage is contained in a structure. In order to obtain quantitative results about size, depth, and overall acceptability of a part, other NDT methods (often ultrasonic testing) are necessary. Another drawback of AE stems from loud service environments which contribute extraneous noise to the signals. For successful applications, signal discrimination and noise reduction are crucial.

2.4.1 AE sources

Acoustic emissions can result from the initiation and growth of cracks, slip and dislocation movements, twinning, or phase transformations in metals. In any case, AE's originate with stress (Catlin, 1983). When a stress is exerted on a material, a strain is induced in the material as well. Depending on the magnitude of the stress and the properties of the material, an object may return to its original dimensions or be permanently deformed after the stress is removed. These two conditions are known as elastic and plastic deformation, respectively.

The most detectible acoustic emissions take place when a loaded material undergoes plastic deformation or when a material is loaded at or near its yield stress (Catlin, 1983). On the microscopic level, as plastic deformation occurs, atomic planes slip past each other through the movement of dislocations. These atomic-scale deformations release energy in the form of elastic waves which "can be thought of as naturally generated ultrasound" traveling through the object. When cracks exist in a metal, the stress levels present in front of the crack tip can be several times higher than the surrounding area. Therefore, AE activity will also be observed when the material ahead of the crack tip undergoes plastic deformation.

AE source in metal were classified into macroscopic source, microscopic source and pseudo source, (Kalyanasundaram, 2007). The different between macroscopic and microscopic source is the size and the amount of elastic energy released from those sources. Activities in material such as relative movement of grain, crack initiation, and crack propagation were classified as a macroscopic source. In the previous work by (Berkovits and Fang 1995a; 1995b; Qiong Ai et.

al, 2010; Yusof et. al, 2012) it was shown that during the fatigue crack formation acoustic emission was emitted with the large amount of energy.

Acoustic emissions can also being generated from the pseudo source. Pseudo source were define as the source from the interaction of outside activities with the materials. Example of happening is through leakage, fatigue crack closure phenomena, vibration from loose component and friction

Two sources of fatigue cracks also cause AE’s, (Kalyanasundaram, 2007). The first source is emissive particles (e.g. nonmetallic inclusions) at the origin of the crack tip. Since these particles are less ductile than the surrounding material, they tend to break more easily when the metal is strained, resulting in an AE signal. The second source is the propagation of the crack tip that occurs through the movement of dislocations and small-scale cleavage produced by triaxial stresses.

The amount of energy released by an acoustic emission and the amplitude of the waveform are related to the magnitude and velocity of the source event. The amplitude of the emission is proportional to the velocity of crack propagation and the amount of surface area created. Large, discrete crack jumps will produce larger AE signals than cracks that propagate slowly over the same distance.

CHAPTER 3

METHODOLOGY

3.1 Flow Chart

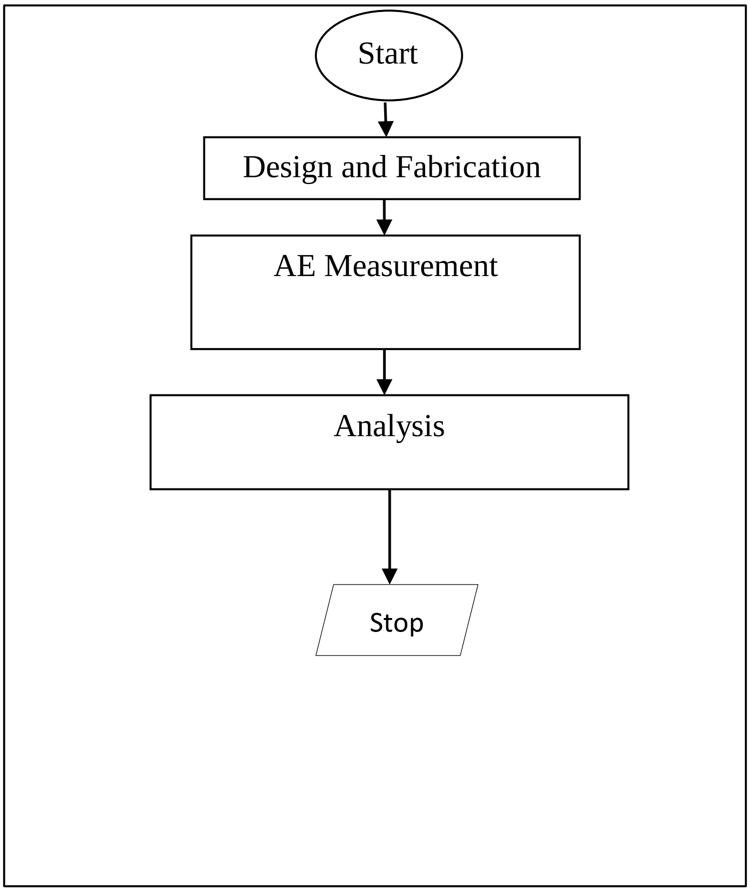


Figure 3.1: Flow of Research

Figure 3.1 shows the flow of the research. During design and fabrication, designation of test rig was done according to specification done by Miller in the year

1999. The fabrication was done upon the confirmation of design with the center part and gasket exchangeable so that the fine part can be exchanged with parts that have defects. AE measurement is done using AEwin for USB software by MISTRAS. For analysis, AE count is observed during different pressure, frequency and dominant frequency were also discussed in analysis. The research is stopped upon the completion of conclusion and recomendation

3.2 Design and Fabrication

A test rig was designed and fabricated for the purpose of sensing the leakage on the pipeline.

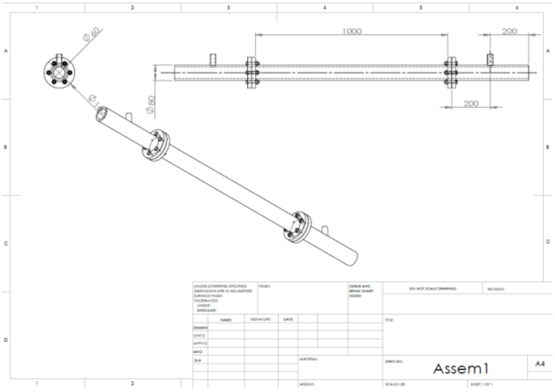


Figure 3.2: Test Rig

Figure 3.2 shows the test rig designed for the purpose of carrying out the experiment. The middle part of the test rig is changeable for different defects to be sensed. The pressure gauge is placed at the two ends of the test rig to make sure the pressure is as wanted.

The calculation is done using, hoop stress:

$$\sigma = \frac{Pr}{t} \tag*{3.1}$$

Maximum allowable stress over safety factor

$$\sigma allowable = \frac{\sigma\ yield\ stress}{SF} \tag*{3.2}$$

$$Hoop\ Stress, \sigma < Maximum\ Allowable\ Stress\ over\ Safety\ Factor, \sigma \max allowable$$

$$\sigma < \sigma \max allowable \tag*{3.3}$$

$$\sigma < \frac{\sigma\ yield\ stress}{SF} \tag*{3.4}$$

$$\frac{Pr}{t} < \frac{\sigma\ yield\ stress}{SF} \tag*{3.5}$$

The complete calculation is attached in appendix A.

3.3 Leakage Size on Test Rig

Figure 3.3: Pinhole Size for Leakage

Figure 3.3 shows the pinhole done for the purpose of leakage detection. The size of 0.7mm has been determined to be used to detect leakage on pinhole. The pinhole would be used for leakage detection in the experiment.

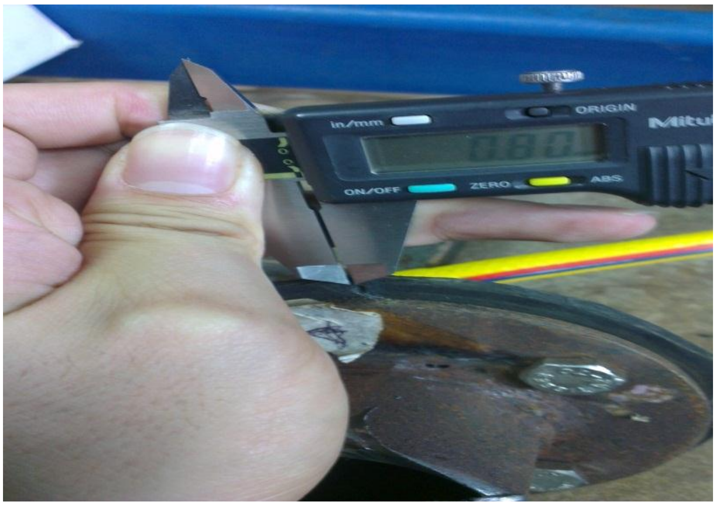


Figure 3.4: Gasket Cut for Leakage Purposes

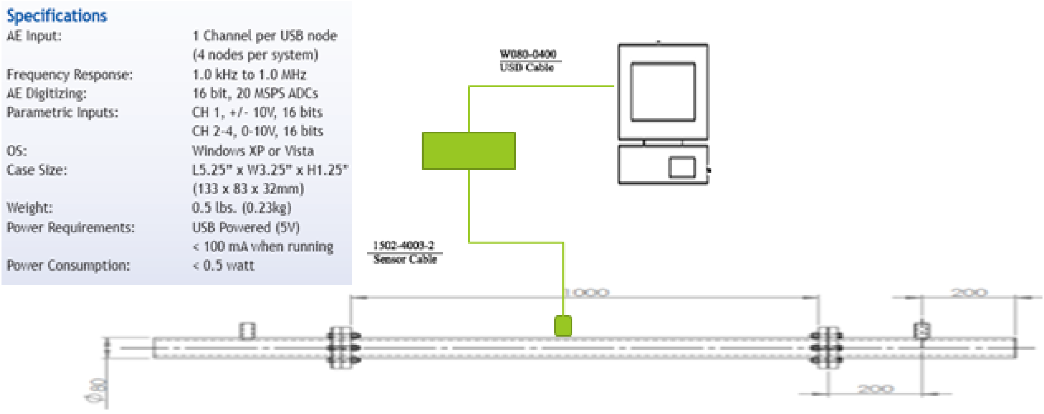
Figure 3.4 shows the gasket cut done for leakage detection purposes. The dimension has been determined to be 0.8mm. The small dimension is to test the capability of acoustic emission to detect minor leakages.

\

Figure 3.5: Size of thread at pressure gauge

Figure 3.5 shows the size of thread at pressure gauge where thread leakages happen. 0.7mm is the size that is used on the thread of the pressure gauge.

3.4 Experiment Setup



Specifications

AE Input:	1 Channel per USB node (4 nodes per system)
Frequency Response:	1.0 kHz to 1.0 MHz
AE Digitizing:	16 bit, 20 MSPS ADCs
Parametric Inputs:	CH 1, +/- 10V, 16 bits CH 2-4, 0-10V, 16 bits
OS:	Windows XP or Vista
Case Size:	L5.25" x W3.25" x H1.25" (133 x 83 x 32mm)
Weight:	0.5 lbs. (0.23kg)
Power Requirements:	USB Powered (5V) < 100 mA when running
Power Consumption:	< 0.5 watt

Figure 3.6: Experiment Setup

Figure 3.6 shows the experiment setup for the research. For most acoustic sources, the sound emission is a consequence of complex internal mechanisms which force machine parts to vibrate which then radiate into the ambient air (airborne sound), or pass vibrations through liquid-filled systems such as pipes (fluid-borne sound), or re-excite connected and supporting structures (structure-borne sound). The present work is devoted to the last case of emission, the structural acoustic transmission. ASME section II Carbon Steel SA-106 Grade A is used in making the test rig and the flow of medium and pressure are regulated by adjusting the valves on the inlet line. The system is designed to allow, in the future, for varying pipe-diameters, pipe material and pipe lengths. The model system is comparable in purpose to the test system described by (Miller, 1999) but limited to laboratory use. Thread, pinhole and gasket leakages are tested in this experiment. According to The U. S. Department of Transportation's Research and Special Programs Administration, Office of Pipeline Safety, pinhole leakages are caused by pitting corrosion that has been the biggest contributor to the pipeline accidents in the United States. Thread and gasket leakages are leakages that are hard to be sensed by other types of method, showing the importance of analysing them in the research. The sensor is linked to analog to digital converter before it reaches the computer. The specification of the analog to digital converter is also shown. The sensor would pick up acoustic emission from the test rig, signal would then be digitise in the analog to digital converter before being shown in the form of graph in through AEwin for USB software by MISTRAS.

3.5 Procedure of Experiment

According to ASME article 5 112, the test rig has to be pressurised to 50% of the maximum pressure, hold for 10 minutes, pressurised to 65% of the maximum pressure, hold for another 10 minutes, pressurised to 85% of the maximum pressure, hold for 10 minutes, pressurised to 100% of the maximum pressure and hold for 30 minutes.

The procedure was done three separate times with the sensor placed at the center of the test rig under three different conditions, namely during the no leak condition, the gasket leakage condition and the pinhole leakage condition. The acoustic emission generated during the whole process would be generated and plotted using AEwin software.

The generated data was then analysed using MATLAB to generate the time domain signal and frequency domain signals according to the generated data.

CHAPTER 4

RESULT AND ANALYSIS

4.1 NO LEAK CONDITION

AEwin for USB software by MISTRAS was used to detect the acoustic emission generated during the experiment.

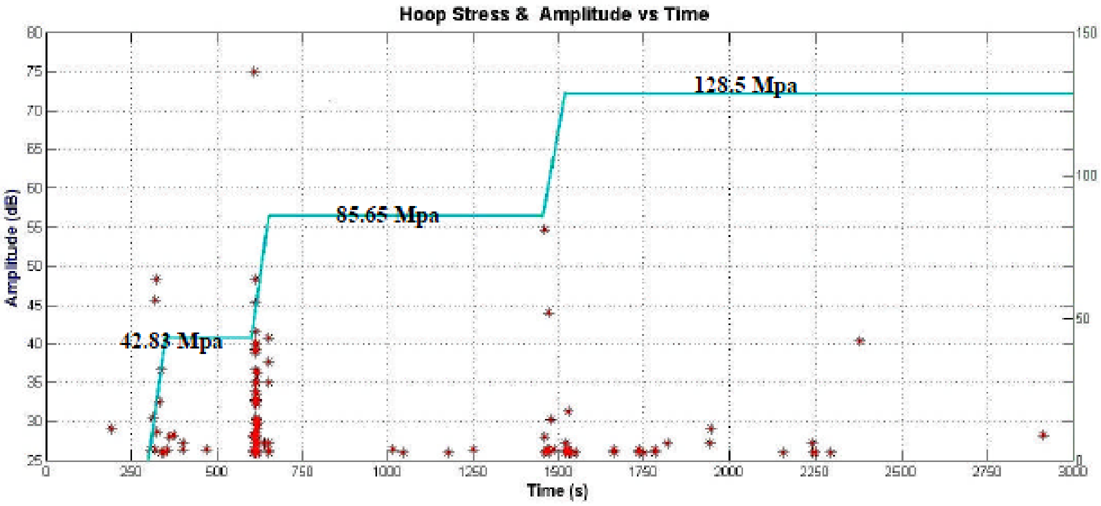


Figure 4.1: Hoop Stress & Amplitude vs Time for no leakage

Source: Hanafi, 2003

Figure 4.1 shows the stress and amplitude vs time graph for no leakage condition (Hanafi, 2003). From the graph, it is seen that more acoustic emission were sensed during pressurisation period and little to almost none acoustic emission were sensed during holding period.

4.2 THREAD LEAKAGE

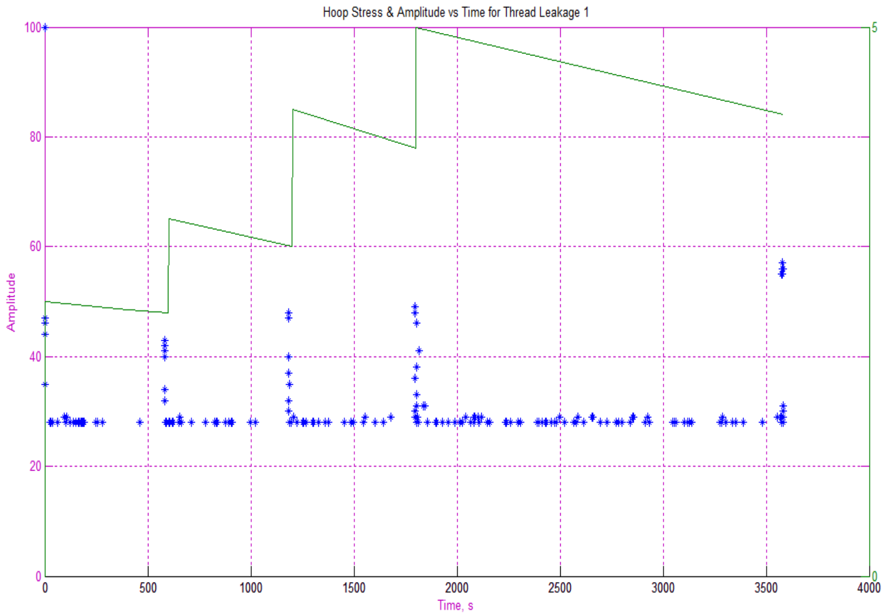


Figure 4.2: Hoop Stress & Amplitude vs Time for thread leakage

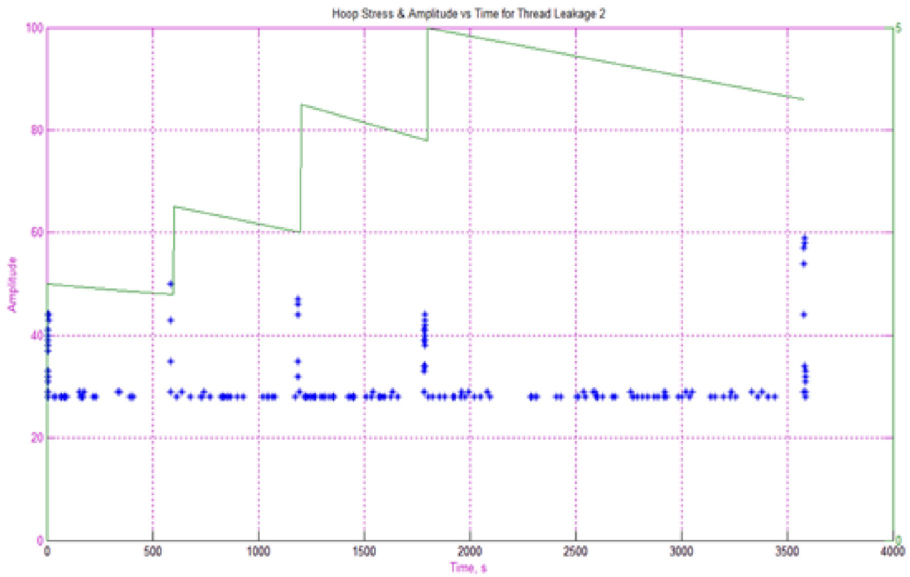
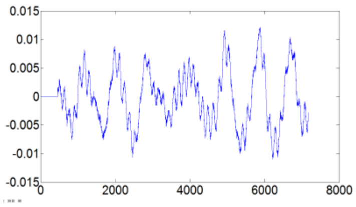
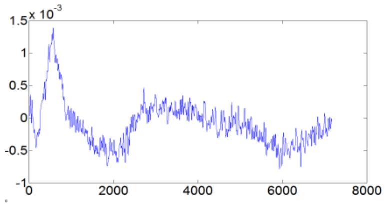


Figure 4.3: Hoop Stress & Amplitude vs Time for thread Leakage 2

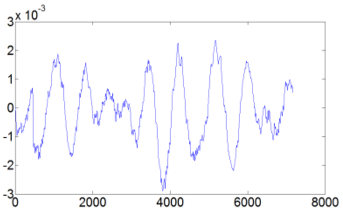
Figure 4.2 and figure 4.3 show the stress and amplitude vs time graph for thread leakage condition. The blue dots shown in graph were the acoustic emission sensed and plotted according to the amplitude. The green line indicates the pressure throughout the whole experiment. The x axis indicates the time of the experiment. From the graph, it is seen that more acoustic emission were sensed during pressurisation period with high amplitude. During the holding period, more acoustic emissions were detected compared to no leak condition as during the holding period, leakage was detected. The leak was caused by the thread at the location of the pressure gauge on test rig.

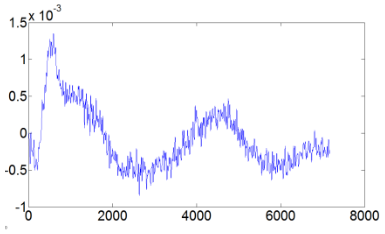




(a)

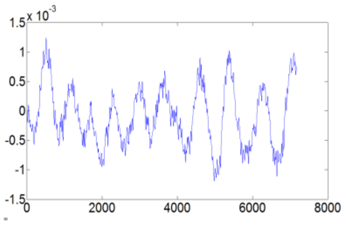
(b)

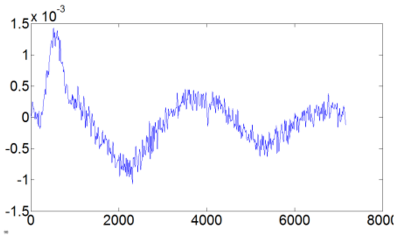




(c)

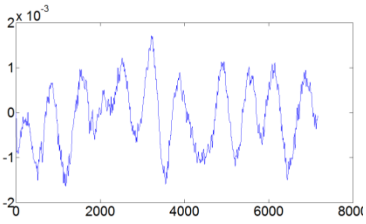
(d)

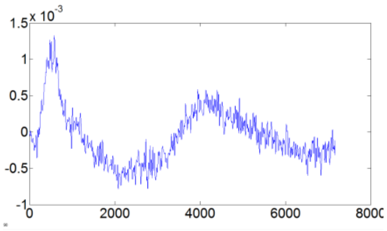




(e)

(f)

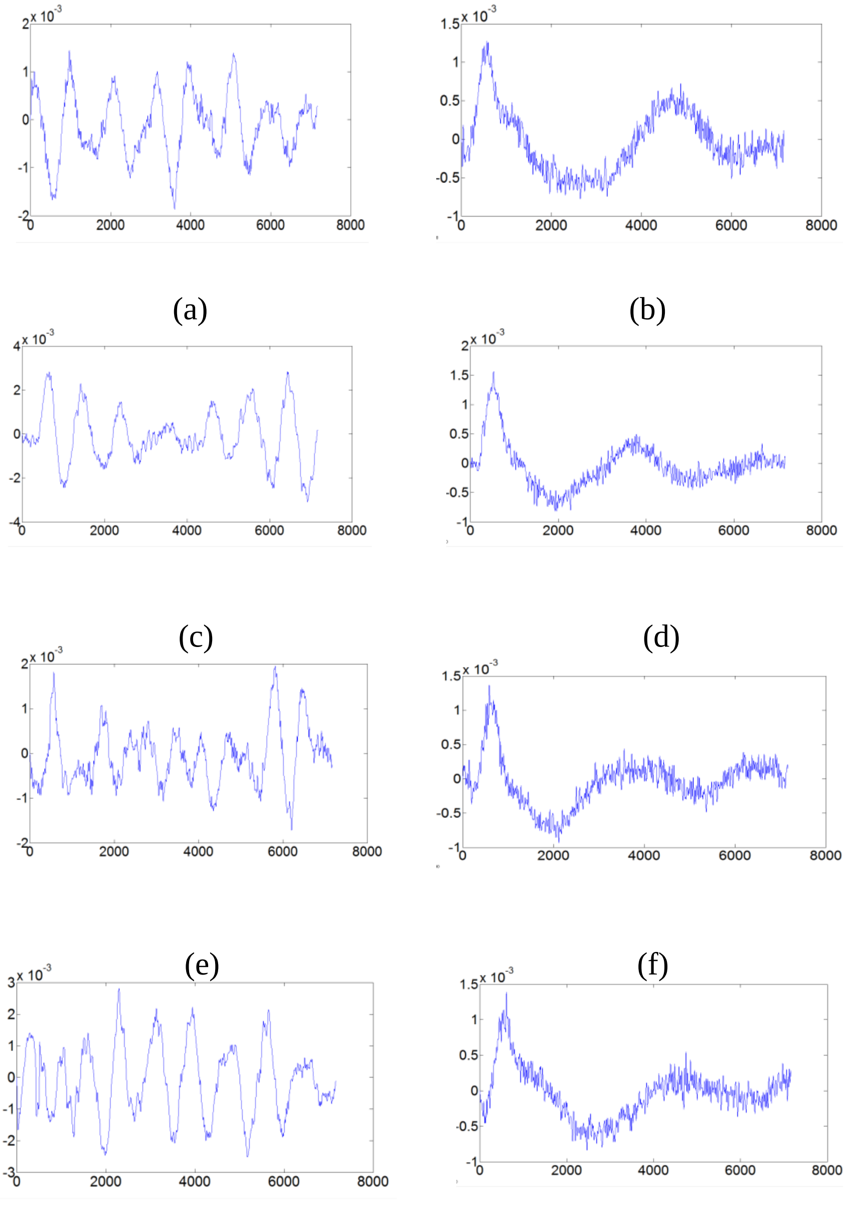




(g)

(h)

Figure 4.4: Time domain signal for thread leakage. (a) First Pressurisation Period (b) First Holding Period (c) Second Pressurisation Period (d) Second Holding Period (e) Third Pressurisation Period (f) Third Holding Period (g) Forth Pressurisation Period (h) Forth Holding Period



(a) (b)

(c) (d)

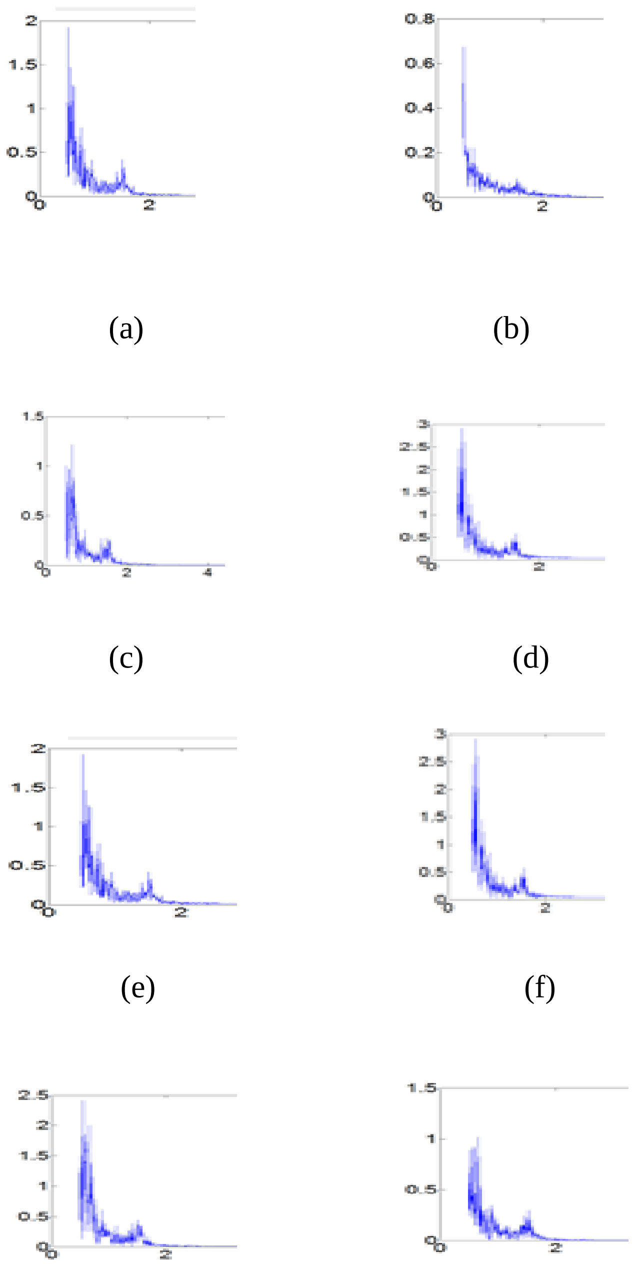
(e) (f)

(g) (h)

Figure 4.5: Time domain signal for thread leakage 2. (a) First Pressurisation Period (b) First Holding Period (c) Second Pressurisation Period (d) Second Holding Period (e)

Third Pressurisation Period (f) Third Holding Period (g) Forth Pressurisation Period (h) Forth Holding Period

Figure 4.4 and figure 4.5 show the time domain signal for both thread leakage experiments. It is noticeable that both experiments show the same pattern. The pressurisation period shows the same pattern as well as the holding period where most acoustic emission detected has the amplitude of 28 or decibel.



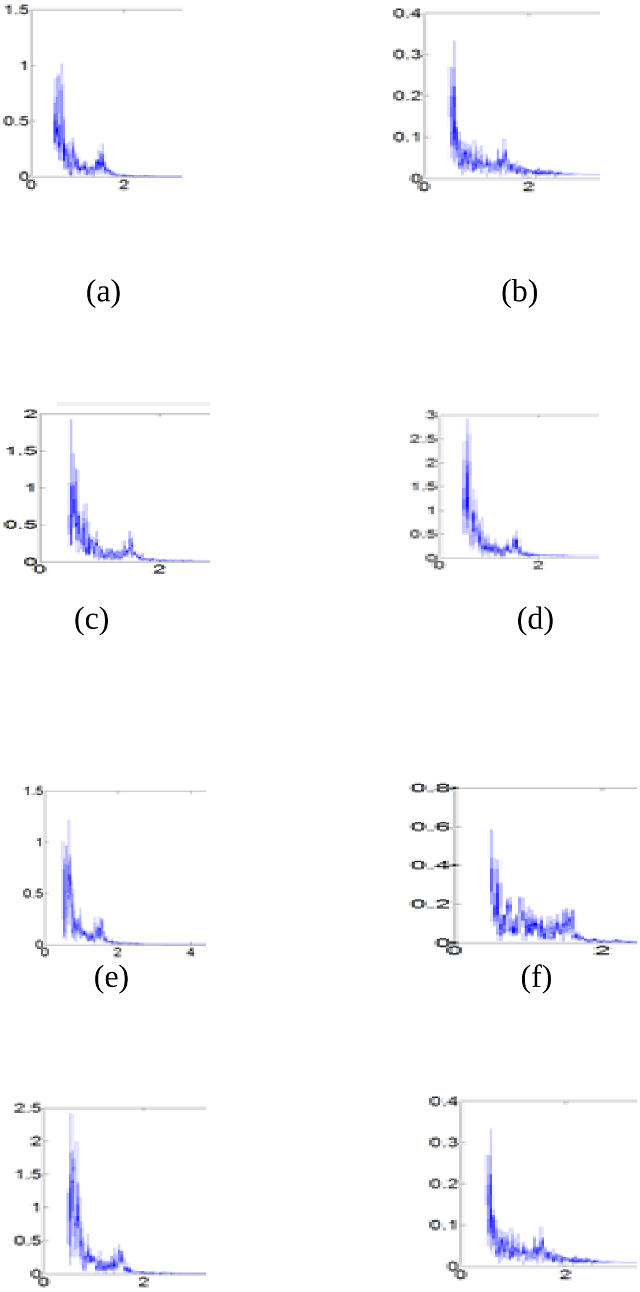
(a) (b)

(c) (d)

(e) (f)

(g) (h)

Figure 4.6 Frequency domain signal for thread leakage. (a) First Pressurisation Period (b) First Holding Period (c) Second Pressurisation Period (d) Second Holding Period (e) Third Pressurisation Period (f) Third Holding Period (g) Forth Pressurisation Period (h) Forth Holding Period



(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

Figure 4.7 Frequency domain signal for thread leakage 2. (a) First Pressurisation Period (b) First Holding Period (c) Second Pressurisation Period (d) Second Holding Period (e) Third Pressurisation Period (f) Third Holding Period (g) Forth Pressurisation Period (h) Forth Holding Period

Figure 4.6 and figure 4.7 show the frequency domain signal for both thread leakage experiments. The data is summarised in table 4.3

4.2.1 Thread Leakage Discussion

.

Table 4.1: Total Number of Acoustic Emission Detected During Holding Period for Thread Leakage

Type of Leakage	**Total number of acoustic emission detected during holding period**
Thread 1	116
Thread 2	120

Table 4.1 shows the total number of acoustic emission detected during holding period for thread leakages. Compared to the no leak condition where very little to almost none was sensed, the number of acoustic emission sensed shows the leak that happened during the holding period at different pressure. The number of acoustic emission detected was small indicating that the leak was not big, (T. Suzuki, 2002). The AE count is directly proportional to the amount of leakage, (M.A. Goodman, 2005)

Table 4.2: Dominant Frequency in Thread Leakage

Period	**Dominant Frequency in Thread 1**	**Dominant frequency in Thread 2**

First pressurization period	5580Hz	5580Hz
First holding period	1395Hz	1395Hz
Second pressurization period	5580Hz	8370Hz
Second holding period	1396Hz	1395Hz
Third pressurization period	5580Hz	8370Hz
Third holding period	1395Hz	1395Hz
Forth pressurization period	4883Hz	4883Hz
Forth holding period	1395Hz	1395Hz

Table 4.2 shows the dominant frequency in the thread leakages. From the dominant frequencies, it is noticeable that the dominant frequencies of pressurisation periods are mostly higher than the holding period as except leakage, air was pumped into the test rig. The dominant frequencies of the holding period of all the experiments are apparently the same at 1395Hz. This says that the leaking during that holding period is constant and air leaks through the hole uniformly.

Table 4.3: Highest Frequency in Thread Leakage.

Period	**Highest Frequency in Thread 1**	**Highest frequency in Thread 2**
First pressurization period	0.19MHz	0.1MHz
First holding period	0.07MHz	0.03MHz
Second pressurization period	0.13MHz	0.19MHz
Second holding period	0.03MHz	0.03MHz
Third pressurization period	0.19MHz	0.13MHz

Third holding period	0.03MHz	0.06MHz
Forth pressurization period	0.24MHz	0.24MHz
Forth holding period	0.01MHz	0.03MHz

Table 4.3 shows the highest frequencies in thread leakages. It is noticeable that the frequencies are ranging around 0.01MHz to 0.12MHz. For Leakage of hole with the dimension of 0.3-1.0mm with pressure of 4-8 bars, the frequency would range between 10-240 kHz, (Brunner, 2006). Frequency of acoustic emission during pressurisation is higher than during holding period due to the fact that during pressurisation, the detected acoustic emissions also come from pressurisation, (R.K. Miller, 1997). That rectifies the data gotten by the experiments. It is also noticeable that highest frequency of the pressurisation period is higher than the highest frequency of the holding period, mainly due to the increase of pressure in test rig.

4.3 PINHOLE LEAKAGE

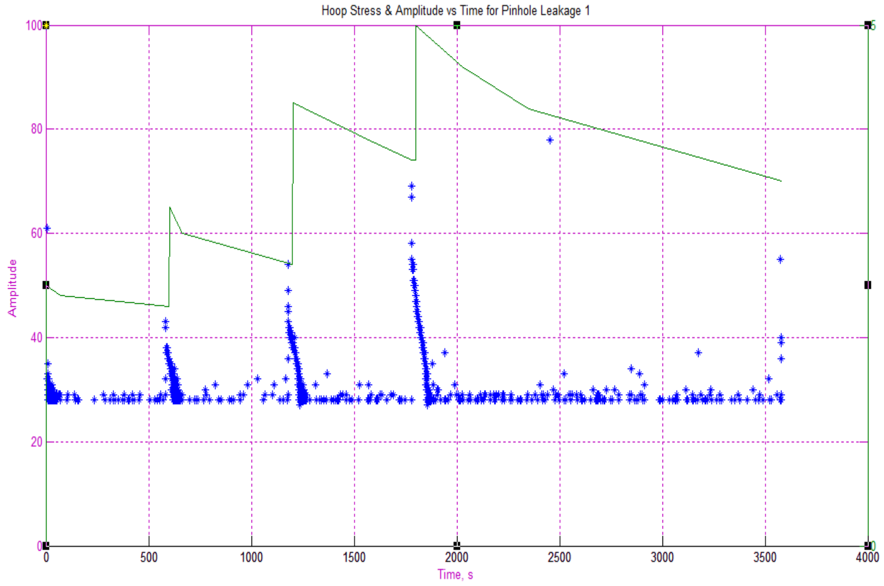


Figure 4.8: Hoop Stress & Amplitude vs Time for pinhole leakage

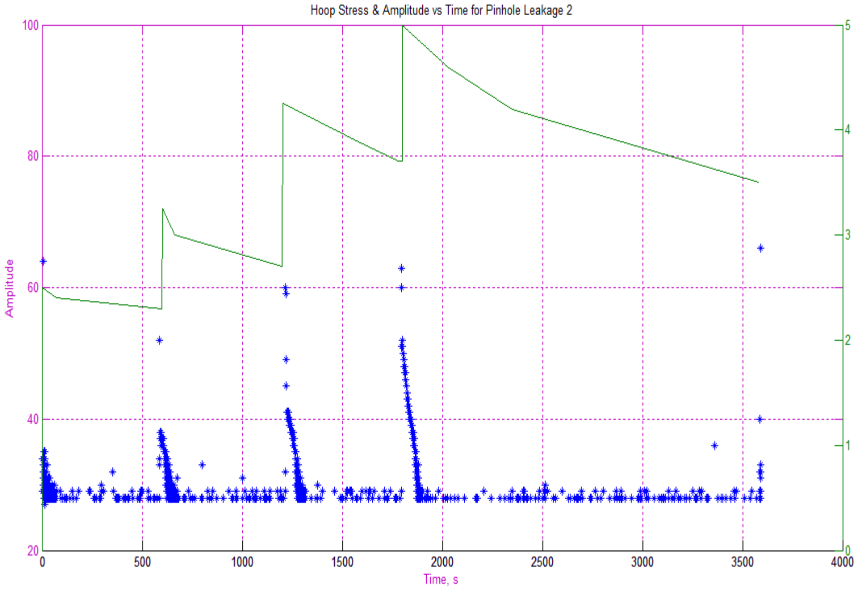
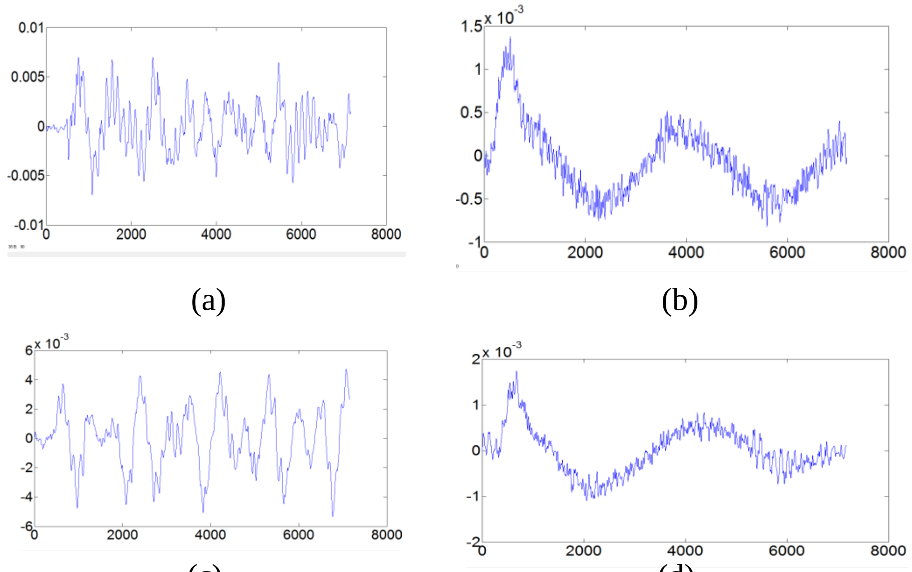


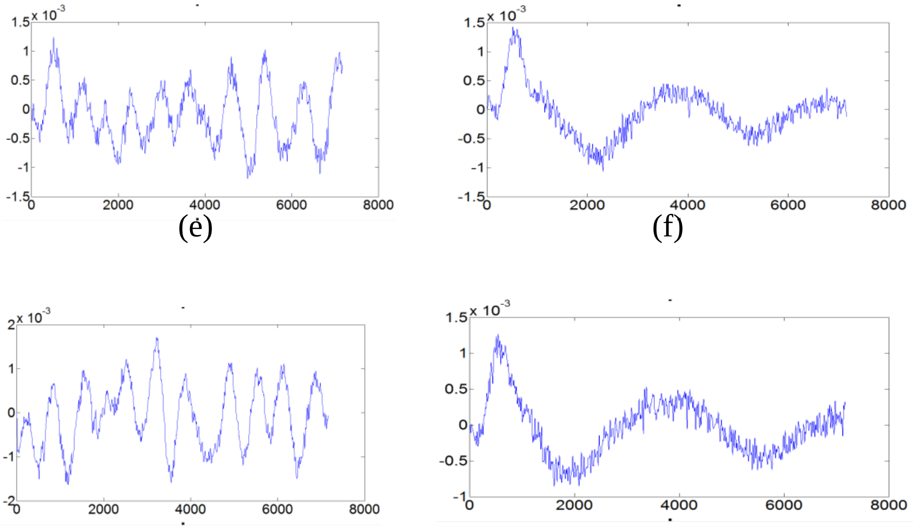
Figure 4.9: Hoop Stress & Amplitude vs Time for pinhole leakages 2

Figure 4.8 and figure 4.9 show the stress and amplitude vs time graph for pinhole leakage condition. The green line shows the pressure of the test rig and the blue dots are acoustic emission sensed during the experiments plotted according to time and the amplitude sensed. From the graph, it is seen that more acoustic emission were sensed during pressurisation period with high amplitude. During the holding period, more acoustic emissions were detected compared to no leak condition and thread leakage as during the holding period, more leakage was detected. The leak was caused by a pinhole at the test rig.



(a) (b)

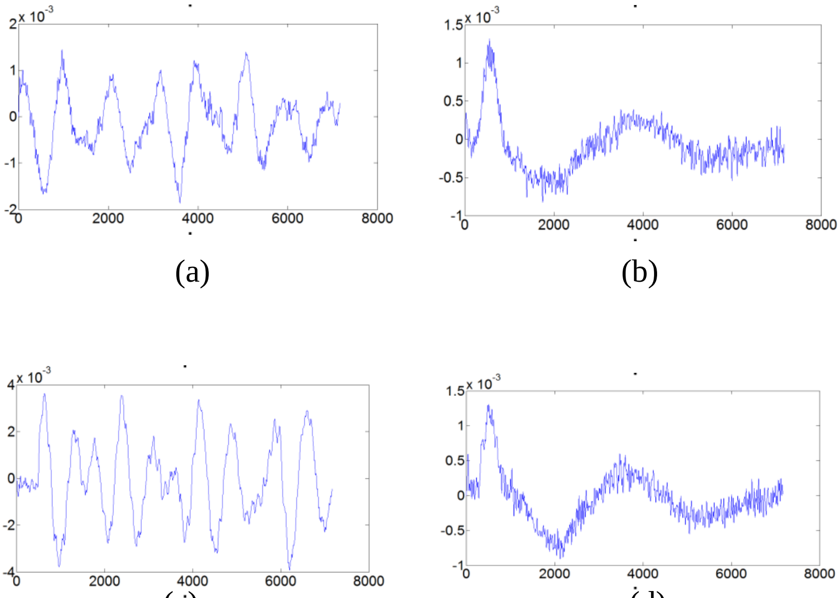
(c) (d)



(e) (f)

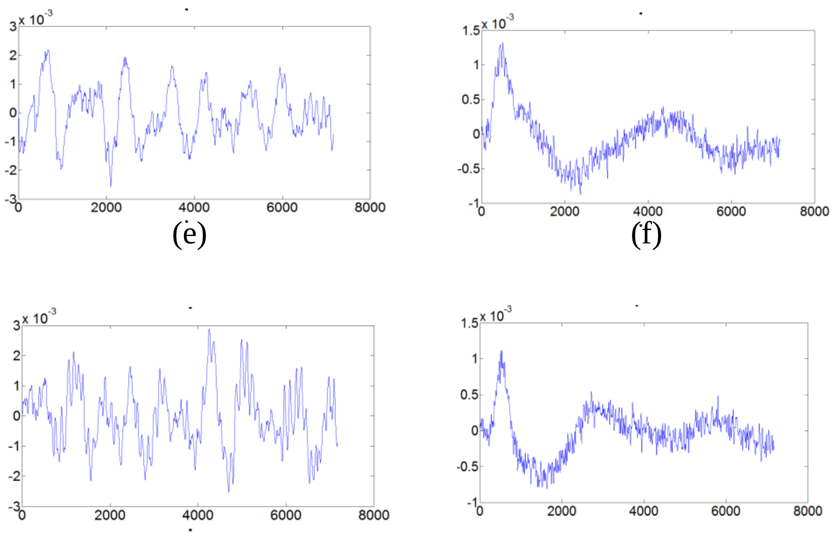
(g) (h)

Figure 4.10: Time domain signal for pinhole leakage. (a) First Pressurisation Period (b) First Holding Period (c) Second Pressurisation Period (d) Second Holding Period (e) Third Pressurisation Period (f) Third Holding Period (g) Forth Pressurisation Period (h) Forth Holding Period



(a) (b)

(c) (d)

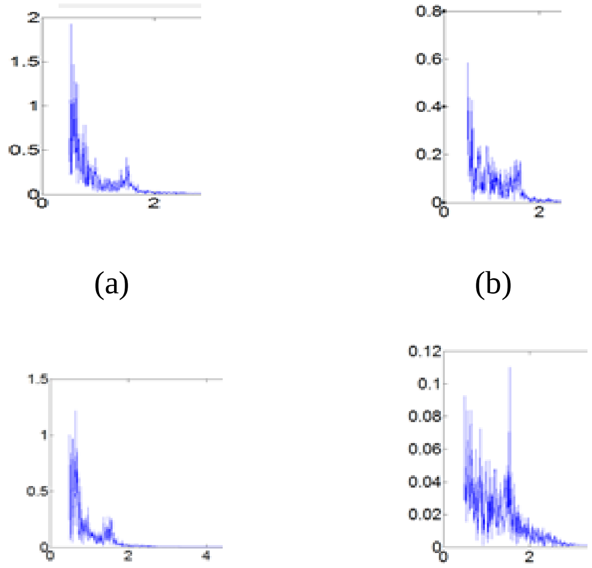


(e) (f)

(g) (h)

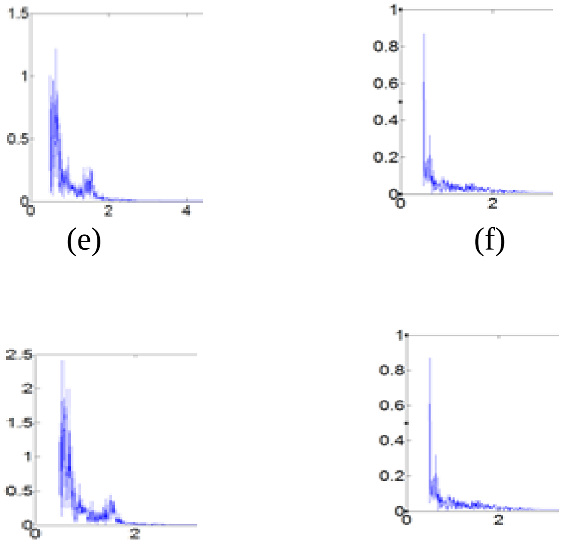
Figure 4.11: Time domain signal for pinhole leakage2. (a) First Pressurisation Period (b) First Holding Period (c) Second Pressurisation Period (d) Second Holding Period (e) Third Pressurisation Period (f) Third Holding Period (g) Forth Pressurisation Period (h) Forth Holding Period

Figure 4.10 and figure 4.11 show the time domain signal for both pinhole leakage experiments. It is noticeable that both experiments show the same pattern. The pressurisation period shows the same pattern as well as the holding period where most acoustic emission detected has the amplitude of 28 or decibel.



(a) (b)

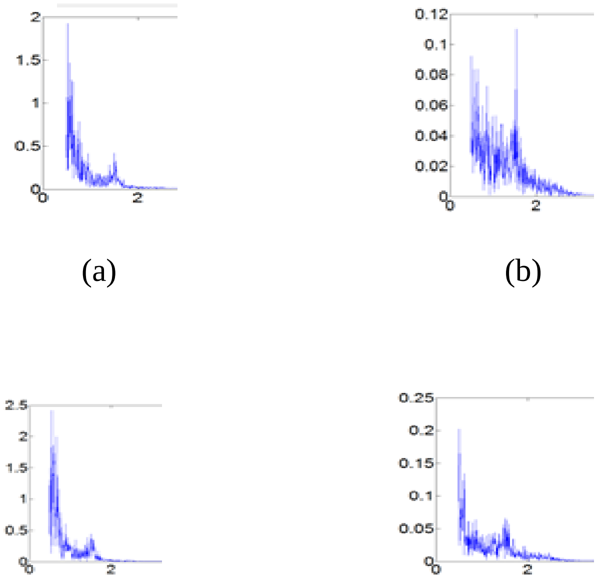
(c) (d)



(e) (f)

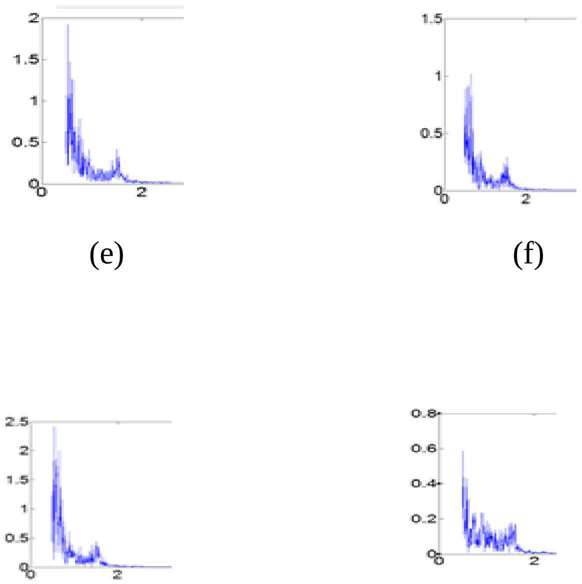
(g) (h)

Figure 4.12 Frequency domain signal for pinhole leakage. (a) First Pressurisation Period (b) First Holding Period (c) Second Pressurisation Period (d) Second Holding Period (e) Third Pressurisation Period (f) Third Holding Period (g) Forth Pressurisation Period (h) Forth Holding Period



(a) (b)

(c) (d)



(e) (f)

(g) (h)

Figure 4.13 Frequency domain signal for pinhole leakage 2. (a) First Pressurisation Period (b) First Holding Period (c) Second Pressurisation Period (d) Second Holding Period (e) Third Pressurisation Period (f) Third Holding Period (g) Forth Pressurisation Period (h) Forth Holding Period

Figure 4.12 and figure 4.13 show the frequency domain signal for both pinhole leakage experiments. The results are summarised in table 4.6.

4.2.1 Pinhole Leakage Discussion

Table 4.4: Total Number of Acoustic Emission Detected During Holding Period for Pinhole Leakage.

Type of Leakage	**Total number of acoustic emission detected during holding period**
Pinhole 1	305
Pinhole 2	294

Table 4.4 shows the total number of acoustic emission detected during holding period for pinhole leakages. Compared to the no leak condition and thread leakage condition, more acoustic emissions were sensed. This is due to the fact that more leakage happened through the hole that is the biggest among all three conditions. The more acoustic emission detected during a time range, the more leak is detected, (T. Suzuki, 2002). The AE count is directly proportional to the amount of leakage, (M.A. Goodman, 2005). This proves that the more leakages happened, the more acoustic emission would be sensed.

Table 4.5: Dominant Frequency in Pinhole Leakage

Period	**Dominant frequency in Pinhole 1**	**Dominant frequency in Pinhole 2**
First pressurization period	5580Hz	5580Hz
First holding period	1395Hz	1395Hz
Second pressurization period	4255Hz	5580Hz
Second holding period	1395Hz	1395Hz
Third pressurization period	5580Hz	5580Hz
Third holding period	1395Hz	1395Hz

Forth pressurization period	3767Hz	3697Hz
Forth holding period	1395Hz	1395Hz

Table 4.5 shows the dominant frequency and highest frequency in the experiments separately. From the dominant frequencies, it is noticeable that the dominant frequencies of pressurisation periods are mostly higher than the holding period as except leakage, air was pumped into the test rig. The dominant frequencies of the holding period of all the experiments are apparently the same at 1395Hz. This says that the leaking during that holding period is constant and air leaks through the hole uniformly.

Table 4.6: Highest Frequency in Pinhole Leakage

Period	**Highest frequency in Pinhole 1**	**Highest frequency in Pinhole 2**
First pressurization period	0.19MHz	0.19MHz
First holding period	0.06MHz	0.01MHz
Second pressurization period	0.13MHz	0.24MHz
Second holding period	0.01MHz	0.02MHz
Third pressurization period	0.13MHz	0.19MHz
Third holding period	0.09MHz	0.09MHz
Forth pressurization period	0.24MHz	0.24MHz
Forth holding period	0.09MHz	0.06MHz

Table 4.6 shows the highest frequency in pinhole leakages. It is noticeable that the frequencies are ranging around 0.01MHz to 0.12MHz. For Leakage of hole with the dimension of 0.3-1.0mm with pressure of 4-8 bars, the frequency would range between 10-130 kHz, (Brunner, 2006). Frequency of acoustic emission during pressurisation is

higher than during holding period due to the fact that during pressurisation, the detected acoustic emissions also come from pressurisation, (R.K. Miller, 1997). That rectifies the data gotten by the experiments. It is also noticeable that highest frequency of the pressurisation period is higher than the highest frequency of the holding period, mainly due to the increase of pressure in test rig.

4.4 GASKET LEAKAGE

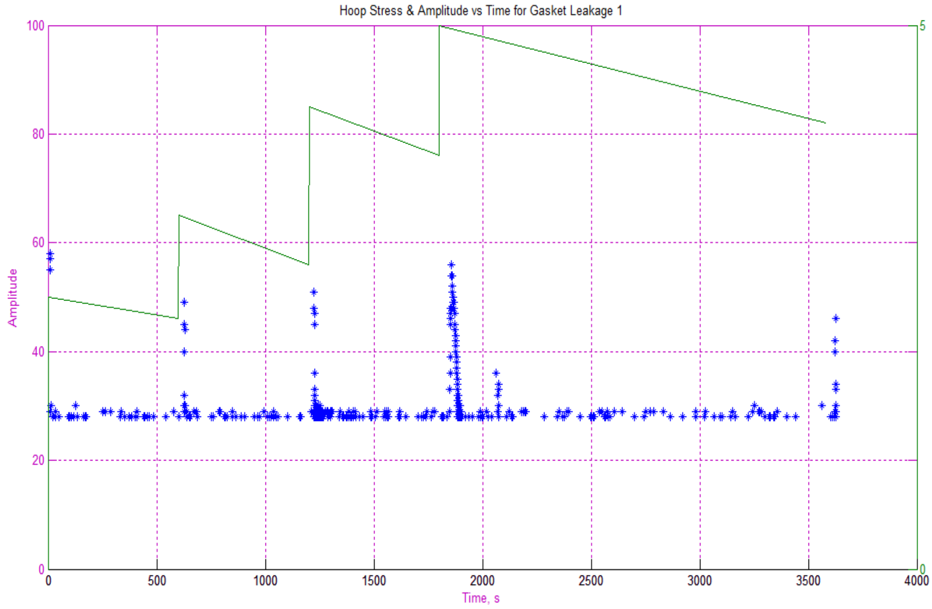


Figure 4.14: Hoop Stress & Amplitude vs Time for Gasket Leakage 1

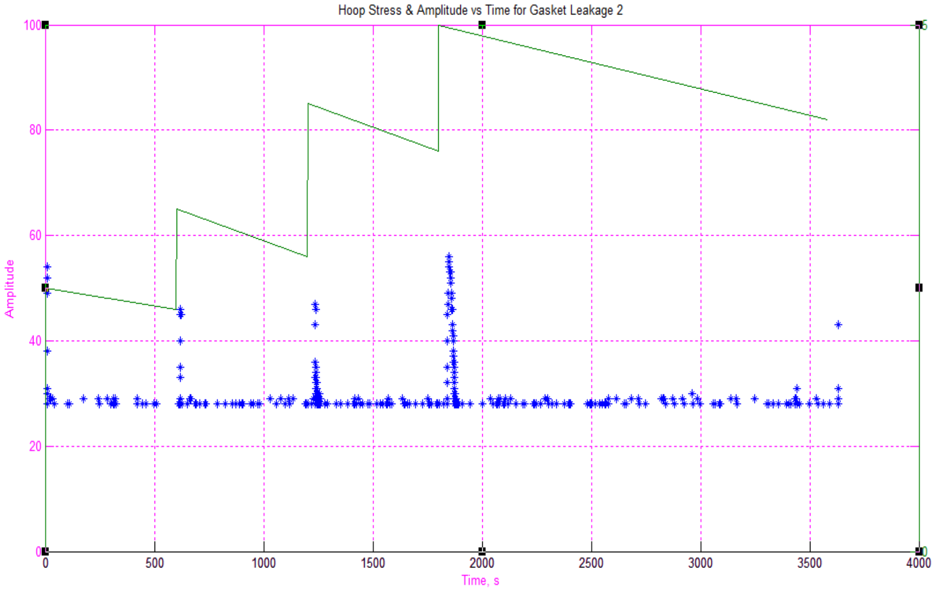
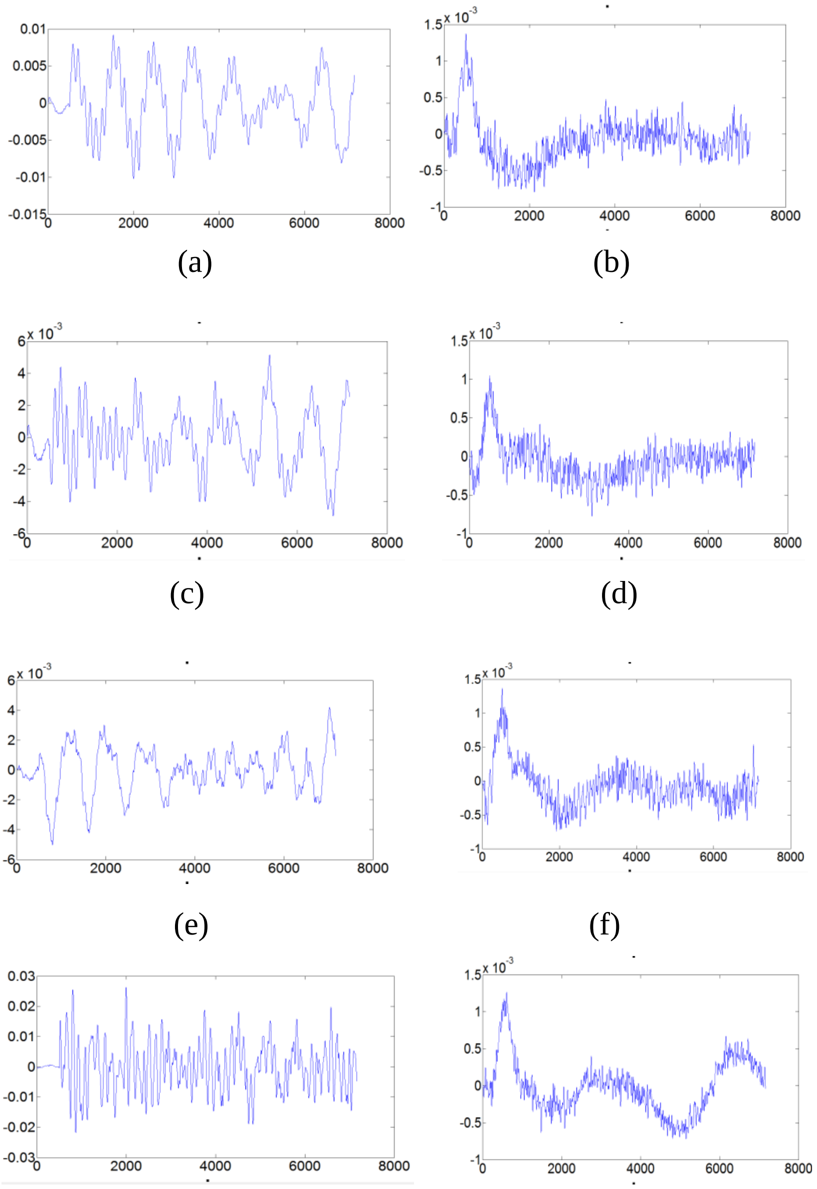


Figure 4.15: Hoop Stress & Amplitude vs Time for Gasket Leakage 2

Figure 4.14 and figure 4.15 show the stress and amplitude vs time graph for Gasket leakage condition. The green line shows the pressure throughout the experiment. The blue dots are acoustic emission detected plotted according to time and amplitude. From the graph, it is seen that more acoustic emission were sensed during pressurisation period with high amplitude. During the holding period, more acoustic emissions were detected compared to thread leakage condition. Nevertheless, the detected acoustic emission detected was lesser than during the pinhole leakage. This is due to the fact that the leakage was lesser than pinhole leakage and more than thread leakage according to the size of defect made. The leak was caused by two gaskets connecting the test rig.



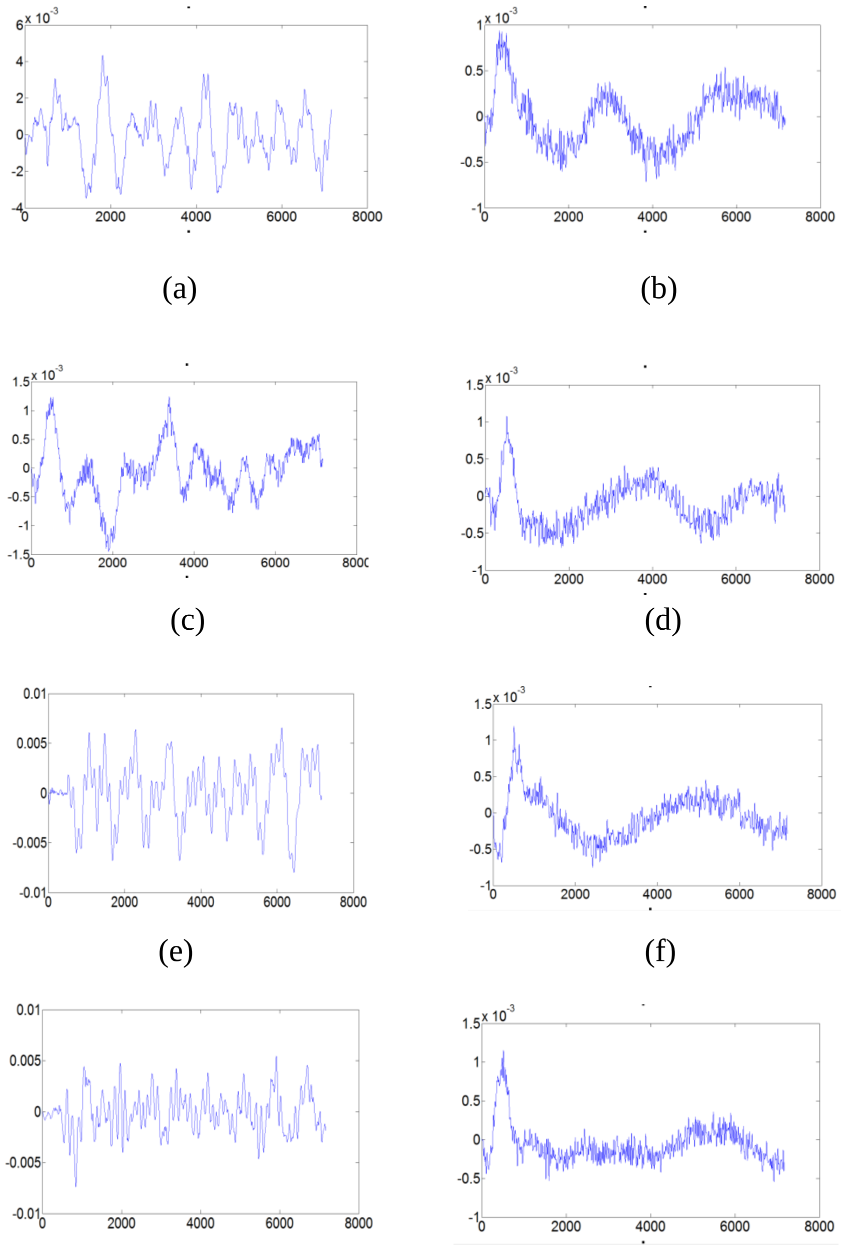
(a) (b)

(c) (d)

(e) (f)

(g) (h)

Figure 4.16: Time domain signal for gasket leakage. (a) First Pressurisation Period (b) First Holding Period (c) Second Pressurisation Period (d) Second Holding Period (e) Third Pressurisation Period (f) Third Holding Period (g) Forth Pressurisation Period (h) Forth Holding Period



(a) (b)

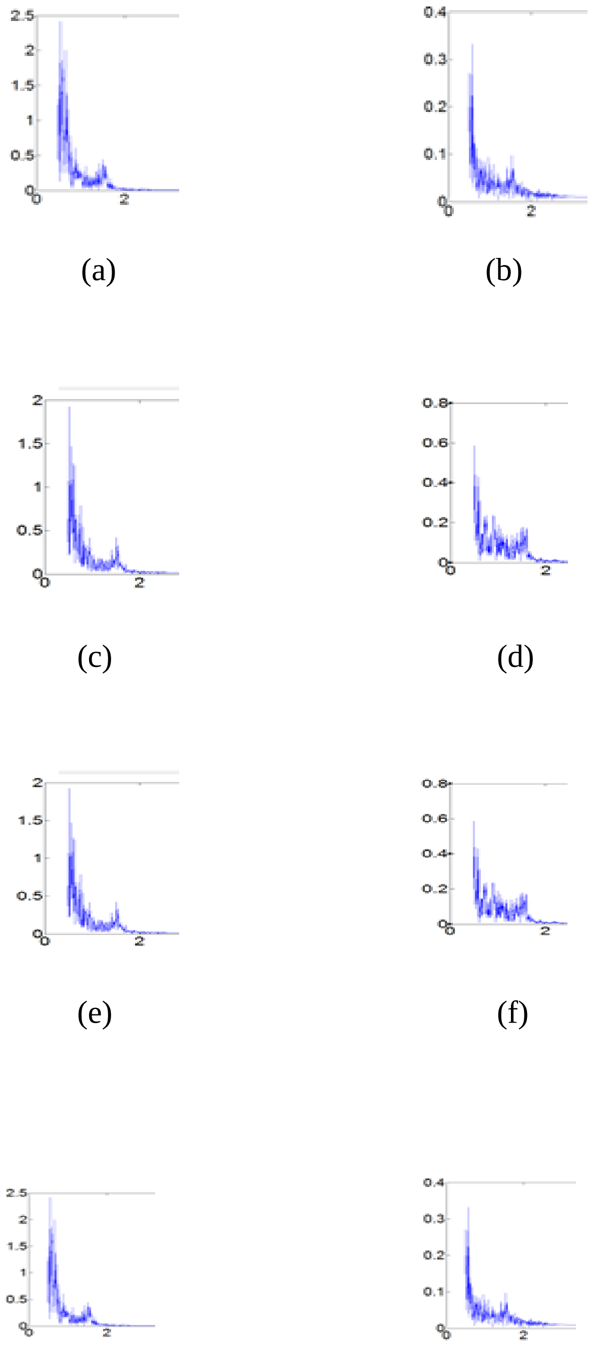
(c) (d)

(e) (f)

(g) (h)

Figure 4.17: Time domain signal for gasket leakage2. (a) First Pressurisation Period (b) First Holding Period (c) Second Pressurisation Period (d) Second Holding Period (e) Third Pressurisation Period (f) Third Holding Period (g) Forth Pressurisation Period (h) Forth Holding Period

Figure 4.16 and figure 4.17 show the time domain signal for both gasket leakage experiments. It is noticeable that both experiments show the same pattern. The pressurisation period shows the same pattern as well as the holding period where most acoustic emission detected has the amplitude of 28 or decibel.



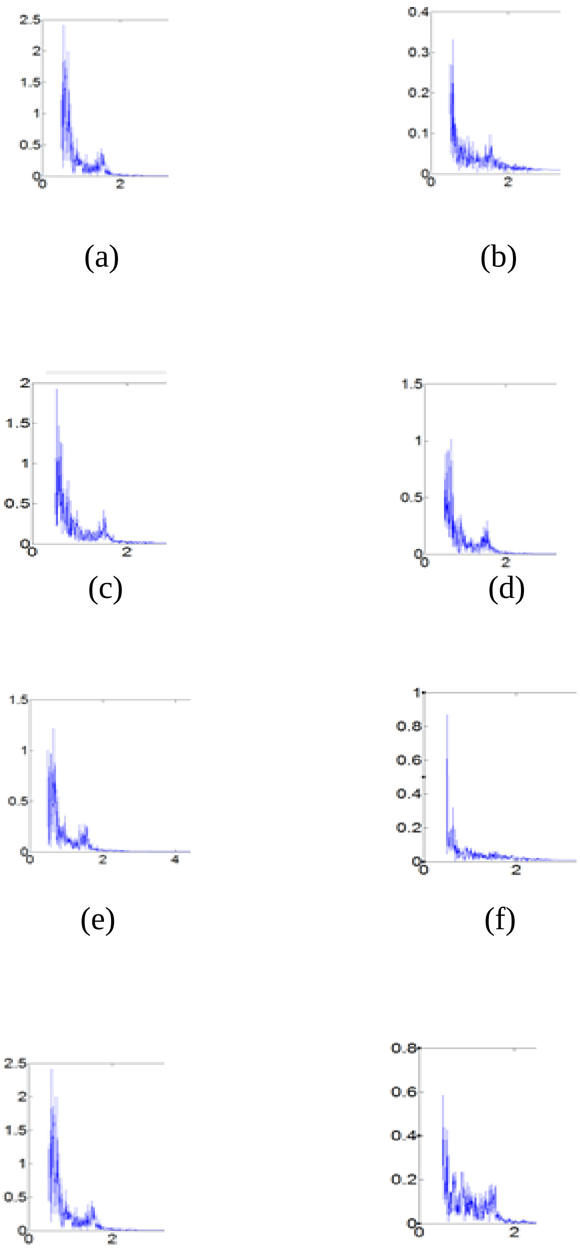
(a) (b)

(c) (d)

(e) (f)

(g) (h)

Figure 4.18 Frequency domain signal for gasket leakage. (a) First Pressurisation Period (b) First Holding Period (c) Second Pressurisation Period (d) Second Holding Period (e) Third Pressurisation Period (f) Third Holding Period (g) Forth Pressurisation Period (h) Forth Holding Period



(a) (b)

(c) (d)

(e) (f)

(g) (h)

Figure 4.19 Frequency domain signal for gasket leakage.2 (a) First Pressurisation Period (b) First Holding Period (c) Second Pressurisation Period (d) Second Holding Period (e) Third Pressurisation Period (f) Third Holding Period (g) Forth Pressurisation Period (h) Forth Holding Period

Figure 4.18 and figure 4.19 show the frequency domain signal for both pinhole leakage experiments. The results are summarised in table 4.9.

4.2.1 Thread Leakage Discussion

Table 4.7: Total Number of Acoustic Emission Detected During Holding Period for Gasket Leakage.

Type of Leakage	**Total number of acoustic emission detected during holding period**
Gasket 1	186
Gasket 2	176

Table 4.7 shows the total number of acoustic emission detected during holding period for gasket leakage. The more acoustic emission detected during a time range, the more leak is detected, (T. Suzuki, 2002). The AE count is directly proportional to the amount of leakage, (M.A. Goodman, 2005). It can be seen from three cases that most leakages happened during the holding period of pinhole leakage experiments followed by gasket experiments and thread experiments. This fits the dimension of leakage where pinhole has the largest dimension of 0.9mm, Gasket 0.8mm and Thread 0.7mm.

Table 4.8: Dominant Frequency for Gasket Leakage.

Period	**Dominant frequency in Gasket 1**	**Dominant frequency in Gasket 2**
First pressurization period	5580Hz	5580Hz
First holding period	1395Hz	1395Hz
Second pressurization period	3245Hz	3245Hz
Second holding period	1395Hz	1395Hz
Third pressurization period	3209Hz	3209Hz
Third holding period	1395Hz	1395Hz
Forth pressurization period	7673Hz	6278Hz
Forth holding period	1395Hz	1395Hz

Table 4.8 shows the dominant frequency of all the periods in gasket leakages. From the dominant frequencies, it is noticeable that the dominant frequencies of pressurisation periods are mostly higher than the holding period as except leakage, air was pumped into the test rig. The dominant frequencies of the holding period of all the experiments are apparently the same at 1395Hz. This says that the leaking during that holding period is constant and air leaks through the hole uniformly

Table 4.9: Highest Frequency for Gasket Leakage.

Period	**Highest frequency in Gasket 1**	**Highest frequency in Gasket 2**
First pressurization period	0.24MHz	0.24MHz
First holding period	0.03MHz	0.03MHz

Second pressurization period	0.19MHz	0.19MHz
Second holding period	0.06MHz	0.09MHz
Third pressurization period	0.19MHz	0.13MHz
Third holding period	0.06MHz	0.09MHz
Forth pressurization period	0.24MHz	0.24MHz
Forth holding period	0.03MHz	0.06MHz

Table 4.9 shows the highest frequency of all the periods in gasket leakage. From the dominant frequencies, it is noticeable that the frequencies are ranging around 0.01MHz to 0.12MHz. For Leakage of hole with the dimension of 0.3-1.0mm with pressure of 4-8 bars, the frequency would range between 10-280 kHz, (Brunner, 2006). Frequency of acoustic emission during pressurisation is higher than during holding period due to the fact that during pressurisation, the detected acoustic emissions also come from pressurisation, (R.K. Miller, 1997). That rectifies the data gotten by the experiments. It is also noticeable that highest frequency of the pressurisation period is higher than the highest frequency of the holding period, mainly due to the increase of pressure in test rig.

CHAPTER 5

CONCLUSION AND RECOMENDATION

5.1 CONCLUSION

The results in Chapter 4 have shown that acoustic emission is able to help the detection of leakage in pipe. The results have also shown that acoustic emission as leakage detection tool is workable for different types of leakage.

The conclusion that can be reached through this study is as follow:

i. Acoustic emission can detect minor leakage up to gasket leakage of 0.8mm, pinhole leakage of 0.7mm and thread leakage of 0.7mm while in operation.
ii. Acoustic emission shows the seriousness of leakage through the number of acoustic emission detected. The more the leakage, the more acoustic emissions generated due to the meeting of the leaked gas and the lips of the leakage hole.
iii. Acoustic emission can detect minor gasket leakages, pinhole leakages and thread leakages effectively

Through the result and discussion made, the objective of the research has been achieved. Gas leakage was detected and through acoustic emission, the seriousness of the leak is able to be determined.

5.2 RECOMMENDATION

The effectiveness of acoustic emission was investigated in this study. However, there are many parameters can be tested to enrich and increase the significance of the study. The recommendations should be considered for the future study. For future work on similar topics, the input below can be taken into considerations:

i. To use more sensors to detect source location of the leakage.
ii. To try the experiment with leakage from smaller size to sense the extent of acoustic emission sensitiveness
iii. To try the experiment with different type of leakage to prove that acoustic emission would work on more types of leakages.
iv. To try the experiment in the industry to make sure the idea of using acoustic emission can work even at the industry pipeline.

REFERENCES

A. J. Brunner, M. Barbezat, Ch. Huber, P Flueler. “ The potential of active fiber composites made from piezoelectric fibres for actuating and sensing applications in structural health monitoring”, Materials and Structures/ Material et Constructions (submitted 2004).

M. Barbezat, A.J. Brunner, M. Melnykowycz, X. Kornmann, Ch. Huber, P. Flüeler, “Inte-grated active fiber composite elements for structural health monitoring in glass fibre reinforced laminates”, *Proc. International Conference on High Performance Structures and Materials, HPSM2004, WIT* Press, Southampton, Southampton, pp. 13-18, 2004.

Amani Raad, Fan Zhang and Menad Sidahmed Leak Detection by Acoustic Emission Using Subspaces Methods, UTC, Laboratoire Heudiasyc, F60205 Compiegne, France

D.S. Kuppermann, T.N. Claytor, T. Mathieson, and D. Prine, Leak-detection technology for reactor primary systems, *Nuclear Safety*, **28**(2), April-June 1987, 191-198.

M.C. Parpaglione, Neural networks applied to fault detection using acoustic emission, *International conference Sao Paolo*, Brasil, 1992, pp. 71-75.

A.J. Brunner, M. Barbezat “Acoustic Emission Monitoring of Leaks in Pipes for Transport ofLiquid and Gaseous Media: A Model Experiment”, Proceedings 27th European Conference on Acoustic Emission, Advanced Materials Research, **13-14**, 351-356, 2006.

ASTM Standard Test Method for Examination of Liquid Filled Atmospheric and Low Pressure Metal Storage Tanks Using Acoustic Emission, E1930-02, American Society for Testing and Materials International, Book of Standards, Vol. 03.03 (annual edition).

T. Suzuki, H. Watanabe and M. Ohtsu (2002), ”Damage Evaluation in Concrete UsingAcoustic Emission Method”, *Proc. The 6th Far-East Conference on Non-Destructive Testing*, JSNDI, Tokyo, pp. 111-116.

N. Nawa, K. Sonoda, H. Iwata and T. Suzuki (2002), ”Survey and Evaluation Method for Deteriorated Agricultural Pipeline Function”, JSIDRE, 70 (12) 31-36.

Cécile Cornu, Study of a cross correlation technique for leak localisation on power primary circuits by acoustic emission, *Commissariat à l'énergie atomique*, France, 1993.

Y. Akematsu, K. Yoshida, K. Sakamaki and K. Horikawa: Progress in Acoustic Emission XI, (The JSNDI, 2002) pp. 319–324.

M. Kotani, H. Hirano and K. Akazawa: SICE. 35 (1999) 554–559.

Baranov, V., Kudryavtsev, E., Sarychev, G. and Schavelin, V. 2007. Acoustic Emission in Friction: Elsevier.

Z.H. Hanafi1, N. Jamaludin, S. Abdullah, M.F. Yusof and M.S. M Zain Evaluation Of Acoustic Emission Behavior Under Hydrostatic Test In API 5L X70 STEEL PIPE *National Conference in Mechanical Engineering Research and Postgraduate Studies (2nd NCMER 2010)3-4 December 2010, Faculty of Mechanical Engineering, UMP Pekan, Kuantan, Pahang, Malaysia; pp. 54-60 ISBN: 978-967-0120-04-1;*

Beattie, A.G. 1983. Acoustic emission, principle and instrumentation. J Acoustic Emission, 2: 95-128.

Kalyanasundaram, P., Mukhopadhyay, C.K. and Subra Rao, S.V. 2007. Practical Acoustic Emission: Alpha Science International Ltd.

Vallen, H. 2006. Acoustic Emission Testing: Fundamentals, Equipment, Application: Castell Publication Inc.

Yoshida, K., Saito, T., Zhu, A., Takagi, H. and Sakamaki, K. 1997. Acoustic Emission Behavior During Tensile Deformation of Ni_3Al Intermetallic Compound, Intermetallic, 6: 1-5.

APPENDIX

P=4bars=4 x 10^5Pa

r=1 inches =2.54 x 10^-2 (ASME Section II Carbon Steel SA-106 Grade A)

$$\sigma\ yield\ stress = 330\ Mpa$$

Safety Factor =1.5

(ASTM Standards/ASME Section II)

$$\frac{4\ x\ 10^{5} pa\ x\ 2.54\ x\ 10^{-2} m}{t} < \frac{330\ x\ 10\hat{}5}{1.5}$$

$$t > 0.000046m$$

$$t > 0.046mm$$

When d= 2 inches, so the available thickness used is 3mm.

Force calculation

$$Density\ of\ Carbon\ Steel, \rho = 7840\ kg/m\hat{}3$$

$$\rho = \frac{W\ kg}{m^{3}(volume\ of\ cylinder)}$$ Equation 3.6

Calculating the volume

$$Volume\ of\ cylinder, v = \pi r\hat{}2$$ Equation 3.7

$$Volume\ of\ cylinder, v = \pi\ x\ (0.0254)^{2} x\ 1$$

$$v = 0.00203m\hat{}3$$

$$7840 = \frac{W}{0.0798}$$

W = 15.89 kg = 155.88N

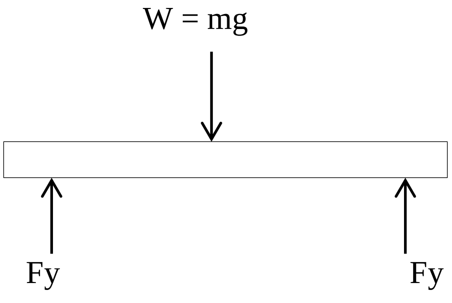


Figure 3.3: Pipeline

1. $\varepsilon Fy = 0$

   $2Fy - W = 0$

   $2Fy = W$

2. $Fy = \frac{W}{2}$

   $Fy = \frac{155.88}{2}$

3. $Fy = 77.94\ N$