KEMENTERIAN PENDIDIKAN MALAYSIA

FINAL REPORT
FUNDAMENTAL RESEARCH GRANT SCHEME (FRGS)

Laporan Akhir Skim Geran Penyelidikan Fundamental (FRGS)
Pindaan 1/2015

A

PHASE:1

YEAR:2013

RESEARCH TITLE: A new technique of leak detection in a gas pipeline network based on time reversal method and non linear acoustic

START DATE:01/04/2013
END DATE (EXPECTED): 31/03/2016

EXTENSION DATE: RMC LEVEL: 30/09/2016
KPM LEVEL:

PROJECT STATUS: (ACTIVE / TERMINATED / COMPLETED)

PROJECT LEADER: Ir Dr Mohd Fairusham Ghazali
I/C / PASSPORT NUMBER: 780708035509

NEW PROJECT LEADER (if any) :
I/C / PASSPORT NUMBER:

PROJECT MEMBERS : (including GRA)

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4. Arman Abdullah
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6. Nurul Fatiehah Adnan (Masters Student-completed)
7. Wan Sofian Wan Hamat @ Wan Safie (Masters Student- on going)
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PROJECT ACHIEVEMENT *(Prestasi Projek)*

B

ACHIEVEMENT PERCENTAGE			
Project progress according to milestones achieved up to this period	**0 - 50%**	**51 - 75%**	**76 - 100%**
Percentage (please state #%)			100%

RESEARCH OUTPUT		
Number of articles/ manuscripts/ books *(Please attach the First Page of Publication)*	**Indexed Journal**	***Non-Indexed Journal***
	2	2
Conference Proceeding *(Please attach the First Page of Publication)*	**International**	***National***
	1	4
Intellectual Property *(Please specify)*	Submitted	

HUMAN CAPITAL DEVELOPMENT					
Human Capital	**Number**				**Others** (please specify)
	On-going		**Graduated**		
Citizen	Malaysian	Non Malaysian	Malaysian	Non Malaysian	
No. PHD STUDENT	1				
Student Fullname: IC / Passport No: Student ID:	Ab Malik bin Awang Hamat@Mohamed PMM13009				
No. MASTER STUDENT	1		1		
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No. UNDERGRADUATE STUDENT			3		
Student Fullname: IC / Passport No:			Najwa Mohamad		

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Student Fullname: IC / Passport No: Student ID:			Akmalariffin Rujikan MA10012		
Student Fullname: IC / Passport No: Student ID:			Khalijah Khalid MC11028		
Total	2		4		

EXPENDITURE *(Perbelanjaan) as Borang K1(RMC)*

C

Budget Approved *(Peruntukan diluluskan)* : **RM 109500**
Amount Spent *(Jumlah Perbelanjaan)* : **RM 107493.81**

Balance *(Baki)* : **RM 2006.19**
Percentage of Amount Spent *(Peratusan Belanja)* : **98.17 %**

ADDITIONAL RESEARCH ACTIVITIES THAT CONTRIBUTE TOWARDS DEVELOPING SOFT AND HARD SKILLS
(Aktiviti Penyelidikan Sampingan yang menyumbang kepada pembangunan kemahiran insaniah)

D

International

Activity	Date (Month, Year)	Organizer
1. 3rd ICMER	18-19 August 2015	UMP, Malaysia
2. ICME	17-18 December 2013	UTHM, Malaysia

National

Activity	Date (Month, Year)	Organizer
1. 8th MUCET Conference	10-11 November 2014	UTEM, Malaysia
2. ICoMEIA	28-30 May 2014	Unimap, Malaysia

E **PROBLEMS / CONSTRAINTS IF ANY** *(Masalah/ Kekangan sekiranya ada)*

At the early stage of research, it is quite difficult to get post graduate student. We manage to get 2 masters students and one PhD student register for this project.

F RECOMMENDATION (*Cadangan Penambahbaikan*)

G RESEARCH ABSTRACT – Not More Than 200 Words (*Abstrak Penyelidikan – Tidak Melebihi 200 patah perkataan*)

This research seeks a new leak detection method based on time reversal wave propagation and nonlinear acoustics – two recent most promising developments from the area of physical acoustics i.e time reversal and nonlinear acoustics. The proposed method attempts to use the so-called nonlinear effect for leak detection in water pipelines. At the end of the research, the propose method is expected to identify features such as leak that present on the pipeline system even on complicated pipeline arrangements with strong noise. Furthermore, comparison with other method approaches will be performed to determine the credibility of the proposed method.

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Date : 18/04/2017
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Project Leader's Signature:
Tandatangan Ketua Projek

H COMMENTS, IF ANY/ ENDORSEMENT BY RESEARCH MANAGEMENT CENTER (RMC)
(Komen, sekiranya ada/ Pengesahan oleh Pusat Pengurusan Penyelidikan)

....

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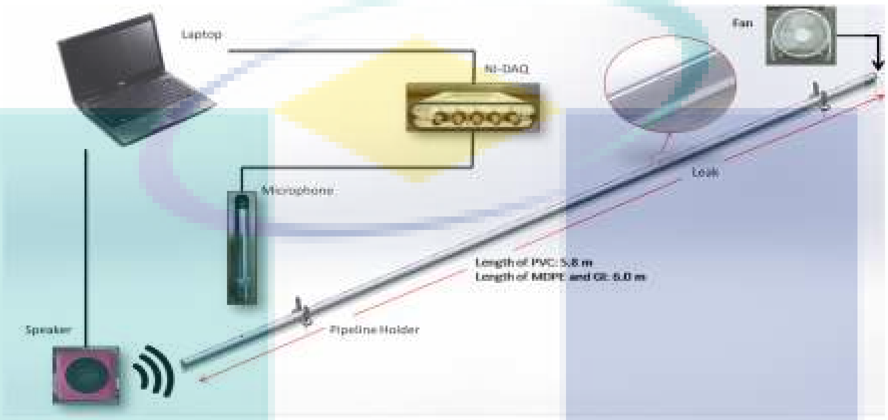
....

Name:
Nama:

Signature:
Tandatangan:

TEMPLATE
BUKU PROFIL PENYELIDIKAN SKIM GERAN PENYELIDIKAN FUNDAMENTAL (FRGS) FASA 1/2013 DAN FASA 2/2013



TITLE OF RESEARCH: A new technique of leak detection in a gas pipeline network based on time reversal method and acoustic

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FRGS Field: Engineering and technology

ABSTRACT (120 words)

This research seeks a new leak detection method based on time reversal wave propagation and acoustics – two recent most promising developments from the area of physical acoustics i.e time reversal and acoustics. The proposed method attempts to use the so-called nonlinear effect for leak detection in water pipelines. At the end of the research, the propose method is expected to identify features such as leak that present on the pipeline system even on complicated pipeline arrangements with strong noise. Furthermore, comparison with other method approaches will be performed to determine the credibility of the proposed method.

1. INTRODUCTION

1.1Project Background

In most application of engineering structure, pipelines are the most important as- pect in completing media transport. Pipelines can be used to transfer air, water, oil and other fluids because of their cost-effectiveness and safety. Pipelines must be reliable, safe and cheap for delivering large volumes of a wide range of refined products from refineries to distant depots (Cerda, 2011). Yet, poor maintenance of the pipelines will result to poor safety conditions and leads to leakages.

Usually, leakages that occurred are caused by damage from nearby excavation equipment, accident, terrorism, earth movement and sabotage. Therefore, leak condition and location of leaks need to be detected as early as possible. Monitoring leak is impor- tant in order to prevent any loss of fluid, that has proven to be costly. In addition, it can prevent any hazardous situation from happening. Recently, researchers have shown an in- creased interest in detection of gas leak after the effects of harmful gases on human health were discovered. There has been dramatic improvement of awareness in the industry on the need to prevent this kind of loss and most importantly assessing the reliability of this industry and safety of the public, employees, environment and to reduce economic losses. In order to accomplish this, the pipeline industry needs to follow the regulations set by governments and strive to find more reliable pipeline inspection systems and that is also cost-effective (Webb, 2015).

Thus, the challenge is to find a leak detection method that is capable of accurately detecting leaks and their location in a timely fashion. As will be presented in the review of the literature in the next chapter, great efforts have been made in order to develop methodologies or devices for determination of leaks, with some limited success.

1.1.1Pipeline System

According to the latest Central Intelligence Agency (CIA) report, there is a total of slightly less than 3.5 million km of pipelines in 120 countries. From that figure, the United States had 65% of them, Russia 8%, and Canada 3%, meaning that 75% of world's pipeline is in these three countries. Our country Malaysia has one of the most extensive natural gas pipeline networks in Asia (Rahim and Liwan, 2012).

Based on Gas Malaysia Berhad (2015), the Peninsular Gas Utilisation (PGU) project which commenced in 1984 is the longest pipeline project in Malaysia spanning more than 2,500 km. The distribution of the pipeline is described as shown in Figure 1.1. The delivery of natural gas is divided into three categories which are industrial, residential and commercial users. The district stations, service stations, area stations and regulating stations is the place to reduce the volume and pressure to the suitable level before being delivered to the customer.

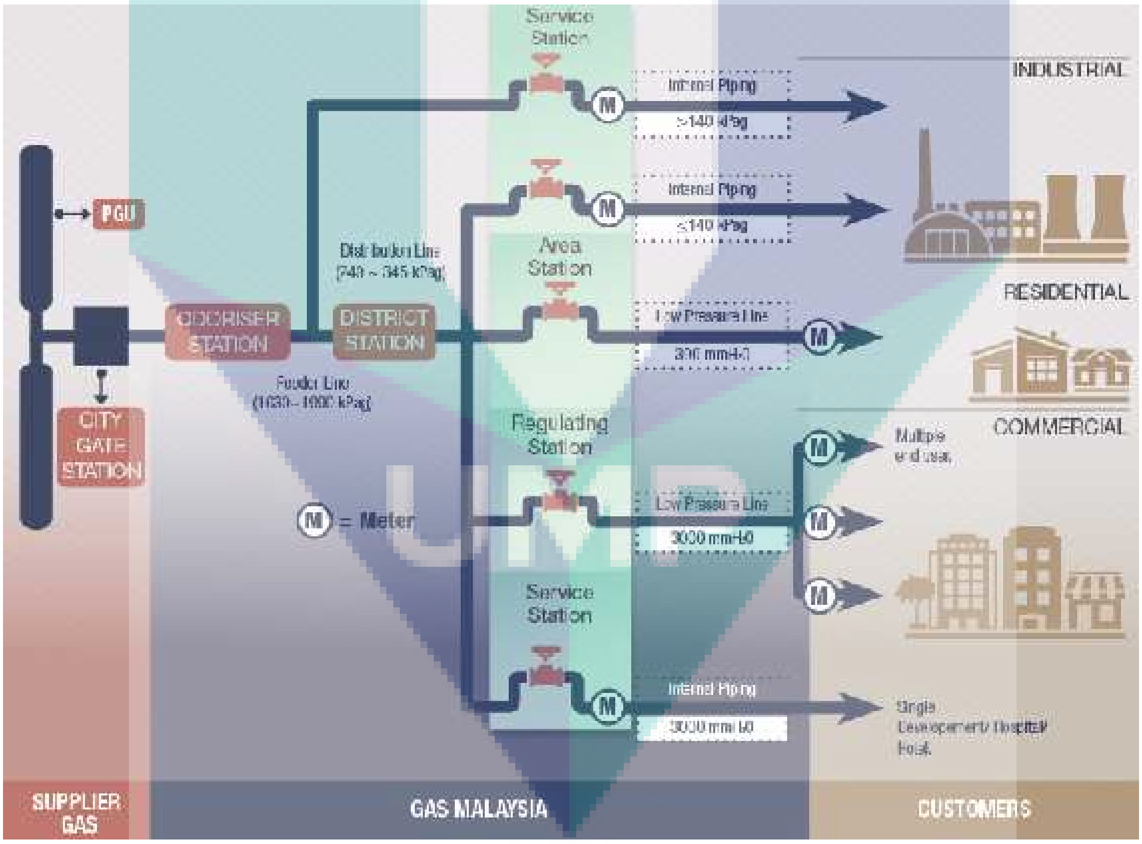


Figure 1.1:Operation process flow

Source: Gas Malaysia Berhad, (2015)

1.1.2Types of Leak

There are many types of leak that can occur in pipelines and piping systems with different types of leak detection methods suitable for each of them. A leak means an unintended crack, hole or porosity in an enveloping wall or joint which must contain or exclude different fluids and gases allowing the escape of closed medium. Rupture is the least common but most dangerous leak. A challenge to the leak detection system and fairly dangerous leak is 'small' hard-to-detect leak. This kind of leak may result from corrosion, erosion, weld or joint failure and fatigue.

Figure 1.2:Example of a pipeline rupture.

Source: Upton, (2014)

1.1.3 Effect of Gas Leaking

Leaks are most likely to occur to older pipelines. The risk of a pipeline accident is fairly small relative to the volume of gas transported. Each year, several trillion cubic feet of gas is transported via approximately 2.5 million miles of pipeline. Large, high capacity pipelines (known as transmission pipelines) are used to move gas from field production and processing areas to local utilities, which then use smaller lines (known as distribution pipelines) to deliver the gas to consumers. Most of the time, the gas is delivered with- out incident. Occasionally however, gas may leak from the pipeline, endangering public safety.

According to Pipeline and Hazardous Material Safety Administration (PHMSA) in the United State, there were 818 accidents that were caused by leaked pipelines resulting to death and personal injury between 1995 to 2014 (Webb, 2015). Recently, an accident occurred in the East Village, near to Manhattan, New York City. It is caused by illegal tap made to the gas main (McGeehan and Ham, 2015).

Other than that, on December 2009, the liquefied petroleum gas (LPG) explosion occurred in a supermarket in Malaysia as reported by Department of Occupational Safety and Health (DOSH). During the accident, workers were making final preparations for the official opening of the complex. The LPG was channelled from the bulk storage tanks through a gas piping network and controlled by a shut-off valve at each of the shop-lot- which is used as food and beverages outlet. Forensic engineering investigation found out that the explosion occurred when a shut-off valve in one of the shop-lots was inadvertently left opened (DOSH, 2011).

Apart from endangering public safety, these accidents are also resulting in finan- cial loss. The loss of the fluid itself can lead to waste. Furthermore, the additional number of cases of death and injuries, gas leakage is truly causing huge loss in term of money, time, and energy. Based on PHMSA report, there have been 10844 accidents reported in the United States as shown in Table 1.1. From 1995 to 2014, the trend has been increas- ing. It is also causing the rise of injuries and fatalities where 96 people were injured and
19 people were died as reported. The pipeline incidents also contribute to the increasing of property damage. The losses are affecting the company and family as well.

Table 1.1
PHMSA Pipeline Incidents: (1995-2014)

Calendar Year	Number	Fatalities	Injuries	Property Damage as Reported ($)
1995	349	21	64	53,427,112
1996	381	53	127	114,467,631
1997	346	10	77	79,757,922
1998	389	21	81	126,851,351
1999	339	22	108	130,110,339
2000	380	38	81	191,822,840
2001	341	7	61	63,092,462
2002	642	12	49	102,167,588
2003	672	12	71	139,057,814
2004	671	23	60	267,836,502
2005	719	17	47	1,245,463,189
2006	639	21	36	151,983,767
2007	613	16	49	154,533,794
2008	659	8	56	565,519,340
2009	628	13	64	179,070,183
2010	588	22	108	1,509,635,198
2011	594	14	56	426,819,470
2012	572	12	57	228,447,641
2013	620	10	47	347,806,517
2014	702	19	96	310,272,540
Grand Total	10844	371	1395	6,388,143,200

1.1.4 Leakage Detection Method

Gas leak is difficult to be detected using plain sight compared to water leakage because of the gas property itself which is colourless and odourless. Figure 1.3 shows the three types of warning sign of gas leak. For long pipelines, it is much more difficult to detect the leak in a short period of time.

The topic of leak detection method is one of the most active areas in gas pipeline research today. As discussed above, there are many methods used in order to detect the leaks effectively. Different methods of leak detection in gas pipeline with different applicability and limitation have been proposed by researchers around the world to ensure safety and efficiency of pipelines (Muhlbauer, 2004). Conventional method such as soap bubble screening and trained dog method is not very effective and have several limitations even though maintenance cost is very low. These methods usually utilize human's or animal's sense. In 2012, many leak detection techniques have been implemented. Murvay and Silea (2012) had differentiated the gas pipeline technique into non-technical method, software based method and hardware based method while Folga (2007) divided into direct or indirect method. With fundamental of leak detection, the leak detection method is improved by the time. The most important detection method is the dynamic signal which is the main theory behind the detection of leaks.

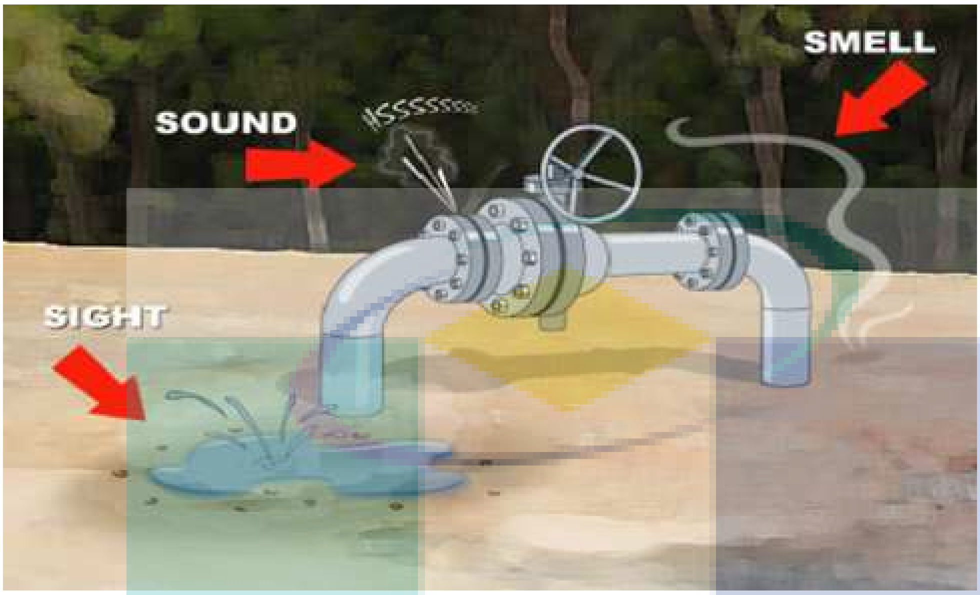
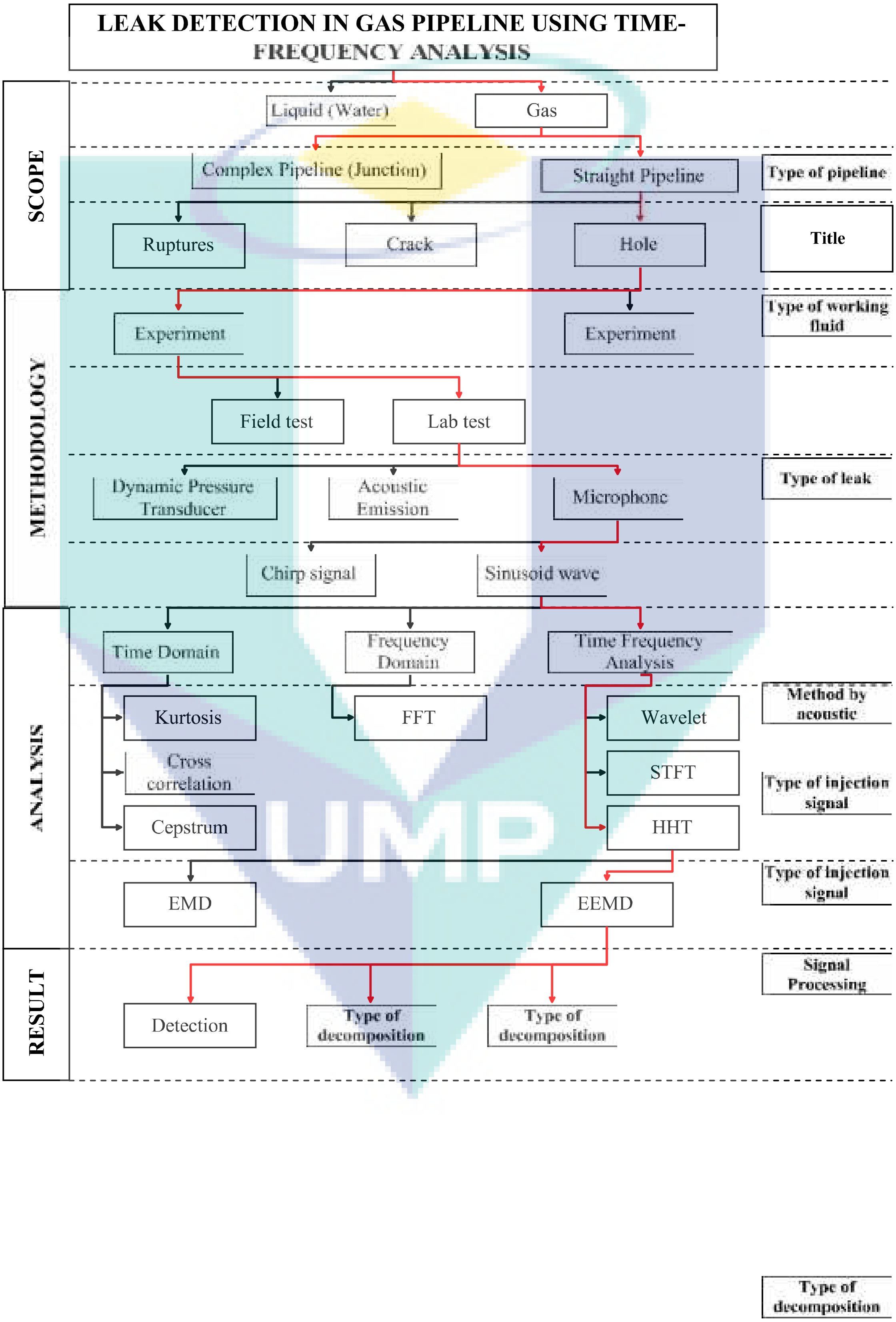


Figure 1.3:Warning signs of gas leaks

Therefore, leak detection is a vital tool for the management of gas pipeline system around the globe. Low false alarm rate and accurate leak location is important part in pre- venting any incident or economic loss. The leak may harm surrounding people, increase the death risk and also decrease the efficiency of the system. Most of them have different advantages, disadvantages, and limitations. The cost of installment is also of the concern to the industry. Therefore, the solution of these problem must be robust with respect to the noise without losing the original signal.

2. RESEARCH METHODOLOGY



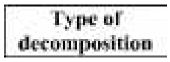


Figure:K-chart of research approached

3. LITERATURE REVIEW

3.1Introduction

A review of previous research efforts related to leak detection methods, sound propagation in pipeline and signal processing is presented in this chapter. This review starts with the definition of leak detection methods and their categories, followed by the fundamentals of sound propagation in gas pipelines including speed of sound and their behavior. Then, the chapter will explain on how sound wave injection into pipelines works. Finally, at the end of this chapter, an overview of signal processing starting from Fourier transform until Hilbert-Huang transform is discussed.

3.2Leak Detection Methods

With the growth in global energy demand, oil and gas production focus on advance technology of leak detection method. The large quantities of medium transported means that a small percentage loss can give rise to events with considerable economic impact, environmental burden associated with wasted energy, and potential risks to public health.

A number of techniques have been developed for gas pipeline lead detection and can be split into software based method and hardware based method. The former con- sists of real time transient modelling (RTTM), mass volume balance, negative pressure wave (NPW), pressure point analysis (PPA), digital signal processing (DSP) and statis- tical method while the latter covers optical method, cable sensor, soil monitoring, vapor sampling, ultrasonic flow meters and acoustic as reviewed by Murvay and Silea (2012). Recently, a new method has been developed called the hybrid technique. Zhang et al. (2015) proposed a novel leak detection method both from software, RTTM and NPW.

3.2.1Leak Detection in Gas Pipelines: Non-Technical Methods

Non-technical method is described as conventional method, using natural sense to detect the leak. Smell or visual effect of the gas maybe be detected at the leakage point in the pipeline. Examples of the method are soap bubble screening and trained dog. For soap bubble screening, the soap is sprayed around the piping joint or valves to detect the leak as shown in Figure 2.1. Aside from, trained dogs are used to detect leaks as they are very sensitive to smell (Kennedy, 2005; Quaife, 1993). Clearly, this method is cheap, and requires no special instrument but the disadvantages of the method is they require experience and meticulous persons to handle the job. However, this kind detection is only applicable for accessible pipelines and not for buried ones.

Figure 2.1:Warning sign of gas leaks using soap bubble screening method

3.2.2Leak Detection in Gas Pipeline: Software Based Methods

Murvay and Silea (2012) had classified software based method as quite similar to indirect method. As the name states, the software algorithm is their main component. These software continuously monitor the changes in pressure, flow rate, temperature and other related paramaters in the pipeline. Next paragraphs will describe on individual soft- ware based method in details.

Real time transient modelling (RTTM) was discovered by Billman and Isermann

(1984). They identified friction parameter in conjunction of cross-correlation of the output estimator error to present the leak detection and localization. Basically, RTTM uses three different equations which are conservation of mass, conservation of angular momentum and conservation of energy. This method can be run in all flow conditions including transient (Xu et al., 2013). Other than that, Morrow and Dickerson (2014) used RTTM through approximation of maximum variation observed in normal running. They analysed the flow and pressure deviation that happened in variation of leaks condition. Hafezi and Mirhosseini (2015) also used this technique to detect water leaks, together with cross correlation method of signal processing in order to detect the leak and find the effect of different size of leak. Even small leaks can be detected using this method, however the cost of instalment is quit expensive because of real-time data collection and the need for trained operators (Scott and Barrufet, 2003).

Next, the mass or volume balance modelling is based on the difference between the upstream and downstream of a pipeline. Liou (1996) and Parry et al. (1992) found that the imbalance between input and output of mass or volume can reveal the existence of leak. This method does not need any generation of high rate of changes in flow and pressure. Fukushima et al. (2000) extended this approach by using mass balance modelling along the pipeline based on transient flow equation. Civan and Balda (2013) applied mass-balance and transient flow models to detect leaks in liquid pipelines. Even though they need to use intensive measurements of all variables, they can estimate the leak location based on it. Other than that, Rougier (2005) used mass-imbalance approach with fully-probabilistic method. However, probabilistic methods need a considerable amount of computational power. Even thought this method is easy to install and has a relatively low cost, the limitation of this method is clear during the shut down, transient, and slack line conditions. In addition, through this method, detection of small leaks are time consuming. According to Doorhy (2011), approximately 60 minutes is needed to detect 1% of leak size.

3.3Acoustic Leak Detection

Leak detection and location in the gas distribution system based on acoustic method has been as a vital research topic both for academics and industry. Acoustic sensor can be used to detect the leaks in pipelines. Operators or intelligent pigs are needed to hold the device along the pipeline to inspect the leak. Placing the sensor too far will increase the risk of undetected leak while placing it too close will increase the cost. Lots of studies have been done in this particular area. Any leak detection method should be quick, accurate, cheap in cost and can be used in normal pipeline without interfering normal operation. Acoustic sensor is normally installed outside the pipeline network. Figure 2.5

shows the overall discussion in this subtopic.

Acoustic leak detection techniques have been studied since the 1930s. Rapid development was done by Watanabe and Himmelblau (1986) and its shows that sharp positive and negative pulse at a certain time using mathematical model of the pipeline acoustic. From this method, they proved that the location of leak is based on the present of sharp pulse or a step at certain time. After that, Rocha (1989) used pressure sensor to record the appearance of acoustic pressure waves. Brodetsky and Savic (1993) presented.

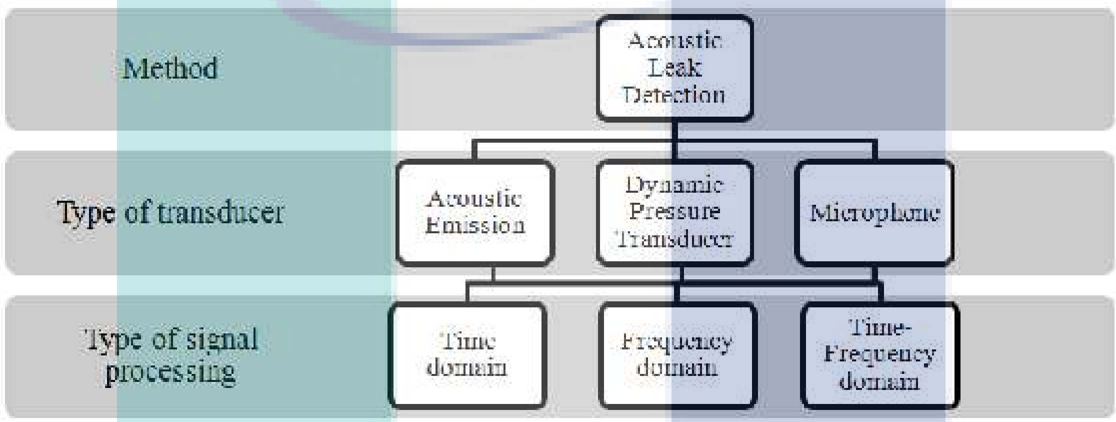


Figure 2.5:Acoustic leak

a new continuous acoustic leak detection system by using k-nearest neighbour classifier to distinguish leaks in underground high pressure gas pipelines. They applied piezoeletric transducer as sensor to detect the force along the pipeline. The standard sound source is produced by a steel ball, falling from 4 inches of height. Mostafapour and Davoodi (2013) used two acoustic emission sensors that transfer through the pipe wall to detect leaks. They removed the noise using wavelet transform and cross correlation algorithm. The result showed that the percentage error is only 5 %.

The technique uses pulse reflectometry involving the injection of sound pulse into the pipeline system and the resulting reflection will be recorded (Sharp and Campbell, 1997). Another study by Tolstoy et al. (2009) also used pulse reflectometry method to investigate pipe irregularities as shown in Figure 2.6. When a blockage is detected in a pipeline, the result shows that the nearer the source of pulse injection to the blockage, the domain strong effect appear and more scattering. Large blockage also gives strong effect compared to smaller ones, while pipe diameter and material will change the backscatter effect. Low frequency impulse is done by Loth et al. (2003) was used to detect leaks involving the measurement of two acoustic signals on each of a pipe segment. Aside from that, a study using cepstrum analysis was developed by using close and open solenoid valve. The time domain was obtained by identifying the delay time between initial wave and their reflections (Taghvaei et al., 2006).

Another experiment used buried pipeline under floors or in the walls of buildings as proposed by Yunus et al. (2006). They intended to provide arrangement information of the pipeline for the reinforcement purpose. Later, Yunus et al. (2008) extended the study in order to detect and locate leak using low cost and easy to implement acoustic method. They developed an experimental and simulation of gas pipeline leakage with

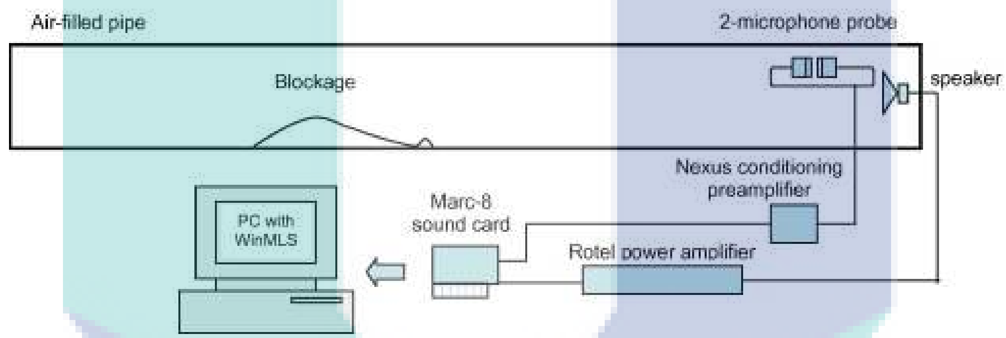


Figure 2.6:Schematic diagram of the acoustic experiment in the pipe

Source: Tolstoy et al., (2009)

different features consist of hole, L-bend, T-bend and crack type. Using Finite Differ- ence Time Domain (FDTD), they presented the suitable frequency characteristic of the signal based on the features and successfully estimated leak location. They discovered the suitable frequency of injected sound is in range of 20-600 Hz for both circular leak and crack type while Murvay and Silea (2012) discovered this method can be used on new as well as on existing pipe network. But, high background noise condition will af- fect the actual leak. Urbanek et al. (2012) used wavelet filter to eliminate noise signal produced by echoes. This method is tuned by maximum value of kurtosis to present the leakage detection and their severity. They concluded that amplitude of echoes is directly proportional with size of hole and decrease with the distance from the hole because of the damping in the medium.

4. FINDINGS

Leak detection is crucial in gas pipeline area for preventing any accident to the surrounding environment. To improve the detection method, acoustic method is proposed in this study. This method includes the analysis of the data using HHT as signal process- ing in time-frequency analysis. Kim and Lee (2009) have concluded that time-frequency technique is the better analysis method compared to power spectral density (PSD). In the study, the time-frequency method was used to explain some of the features of wave propa- gation measurements made in gas pipes. In addition, time-frequency method can identify the cut-off frequencies for acoustic modes in a circular duct. In this study, three types of materials were used for straight pipeline and L-bend feature.

According to Huang et al. (1998), HHT is a robust method to analyze the non-stationary signal. This transformation is especially suited for analyzing non-linear and non-stationary data. HHT consists of two major components which are EMD and HT. However, the limitation in EMD such as the existence of unwanted ripple and mode- mixing problem leads to development of EEMD, which consequently resulting to the addition of noise signal to solve the problem (Flandrin and Goncalves, 2004; Wu and Huang, 2009). The synthetic signal that is performed in sub chapter 3.6 seeks to observe the difference of EMD and EEMD. The result is shown in Figure 3.13 an 3.15 shows a better resolution in EEMD compared to EMD. The unwanted ripple can be eliminated successfully. Mode mixing not only can cause serious aliasing in subsequent IMFs, but also cause individual IMFs to be devoid of physical meaning (Huang and Wu, 2008; Wu and Huang, 2009). The result shows that the obtained IMF1 to IMF3, and IMF8 did not have any meaningful fact.

Polikar (1996) found that FT is not relevant to analyze non-stationary signal as presented in most industrial practice. HT of x(t) produces time-domain signal. One of the advantages obtained with the representation of instantaneous frequency is that frequency can be determined at any given time t, since frequency can be calculated by differentiat- ing the phase angle with respect to time (Huang and Attoh-Okine, 2005) as explained in Chapter 2. Ghazali (2012) also found that HT is the best transformation to present instan- taneous frequency. The proposed method has shown that features and leak points along a pipeline can be determined with only a small error in distance.

Yunus et al. (2008) performed an experimental and simulation of gas pipeline leak- age with different features consists of hole, L-bend, T-bend and crack type. Using Finite Difference Time Domain (FDTD), they presented the suitable frequency characteristic of the signal based on the features and successfully estimated leak location. They discovered the suitable frequency of injected sound is in range of 20-600 Hz for both circular leak and crack type. Wang et al. (2009b) have discussed that the experiment should be done either use low frequency or shorter time duration of injection. This is to get the better result and easy implementation during the experiment. Urbanek et al. (2012) concluded that amplitude of echoes is directly proportional with size of hole and decrease with the distance from the hole because of the damping in the medium.

Pressure balance in the pipeline system can be interrupted when something is blocking the flow. Three effects that is occurred due to the incident wave (Burn et al.,1999; Beck and Staszewski, 2004) are reflection, transmission and absorption (Figure 2.8). Dispersion is the phenomenon of speed change in frequency due to structural and geometric size. Meanwhile, absorption is determined by the material used. Different material shows the difficulties during the analysis especially to find instantaneous frequency and phase. However, HHT is capable to perform satisfied result. The result for without leak and leak is presented in Figure 4.11 and Table 4.2 for MDPE, Figure 4.18 and Table 4.3 for PVC while Figure 4.25 and Table 4.4 for GI pipe. All the result is below than 5 % of error.

Tao et al. (2015) studied on simulation wave propagation within network pipeline system for several branch. When an acoustic wave is propagating towards the branch joint in one of the pipes, part of the signal will be reflected at the branch joint. Wang et al. (2009a) used the signal generated by an acoustic pulse generator to inject the input signal into the pipeline. A 800 Hz sound was injected into the pipe with a bend. In conjunction, his study proposed the L-bend using PVC pipe with 6.8 m total length. The leak location error and also L-bend location is presented in Table 4.5 as well. The leak, L-bend and outlet is clearly presented in HHT as shown in Figure 4.31.

The proposed method has successfully present leak and L-bend location via EEMD and HT with lower than 5 % of error. Other than that, instantaneous frequency and phase can perform acceptable spikes to show the leak location. Due to different absorption rate in material, the result also shows the difficulties in analysing the result. However, clear understanding of time-frequency domain is important to define the leak location accurately.

The experiment was conducted using three different materials which are MDPE, PVC and GI pipelines. The extended experiment was conducted using PVC pipeline with additional L-bend. Preliminary study was done to choose the suitable frequency of sound injection to run in the experiment. As a result, 500 Hz of sound wave is chosen to inject into the pipeline. The instantaneous phase and frequency using HT helps the analysis and EEMD method is proven as an effective technique to filter the noise by removing the un-wanted noise. As shown in previous results, it can be concluded that all of the experiments can removed IMF1-IMF3 and IMF8 before HT is being conducted, including for the L-bend case. The existence of L-bend can be performed by the instantaneous phase and frequency. The results was analysed to be perform in Hilbert spectrum. The percentage error is calculated to measure the accuracy of the leak location. Next chapter will present on the summary of findings, objectives, as well as conclusions for the study. Besides, some recommendations for further studies were also suggested in the same chapter.

5. CONCLUSION

Leak detection and location are vital to prevent any losses in term of financial and energy, ensure safety and control environmental problems. Therefore, effective techniques for leak detection are very important in order to improve these problems. The Hilbert Huang Transform (HHT) with Ensemble Empirical Mode Decomposition (EEMD) was developed and its performance testing had been successfully carried out. The observation on EEMD performance had involved experimental analysis. The experiment was conducted using different materials with different features. The results were analysed using HHT that consists of two components which are Hilbert transform (HT) and EEMD and as has been discussed thoroughly in this thesis. This study has found out that HHT can be alternative advance signal processing method for leak detection application. Thus, some recommendations for future studies were suggested in the last part of this section.

ACHIEVEMENT

i) Name of articles/ manuscripts/ books published

a) Hamat, W.S.W., ***Ghazali, M.F.*** and Priyandoko, G. Ultrasonic Guided Wave Method for Crack Detection in Buried Plastic Pipe, *MATEC Web of Conferences Volume 74, 29 August 2016, 3rd International Conference on Mechanical Engineering Research, ICMER 2015*

b) A.M.A. Hamat, ***M.F. Ghazali***, M.M.Amin and N.F. Adnan, Irregularity Detection in Artificial Signal using Time-Frequency Analysis, *ARPN Journal of Engineering and Applied Sciences*, 11(6) pp 3593-3597

c) N. F. Adnan, ***M. F. Ghazali***, M. M. Amin,A.M.A. Hamat, Leak Detection in Gas Pipeline using Hilbert-Huang Transform, *Applied Mechanics and Materials Vol. 815 (2015) pp 403-407*

d) N F Adnan, ***M F Ghazali***, M M Amin and A M A Hamat, Leak detection in gas pipeline by acoustic and signal processing – A review, IOP Conf. Series: Materials Science and Engineering 100 (2015) 012013 doi:10.1088/1757-899X/100/1/012013

e) N.F. Adnan, **M.F. Ghazali**, M. Amin, A. M. A. Hamat, A. Ariffin, Leak Detection in MDPE Gas Pipeline using Dual-Tree Complex Wavelet Transform ,Australian Journal of Basic and Applied Sciences, 8(15) Special 2014, Pages: 356-360

f) M. Amin, A. Hadi and **M. F. Ghazali** (2014), Leakage Detection in Pipeline using Synchrosqueeze Wavelet Transform, Applied Mechanics and Materials Vols. 465-466 pp 467-471 DOI:10.4028/www.scientific.net/AMM.465-466.467

g) M. Amin and **M. F. Ghazali** (2013) Leakage Detection in pipelines using ensemble empirical mode decomposition analysis, 2nd International Conference on Advanced Manufacturing, Ayodya Resort, Bali, Indonesia, 12-13 December 2013.

ii) Title of Paper presentations (international/ local)

a) M. Amin, **M.F.Ghazali** , Leakage Detection in Galvanized Iron (GI) Pipelines Using Ensemble Empirical Mode Decomposition Analysis (EEMD), International Conference on Mathematics, Engineering & Industrial Applications 2014 (ICoMEIA 2014), Unimap

b) N.F. Adnan and **M.F. Ghazali** Detecting Leak in Gas Pipeline using Continuous Wavelet Transform and Kurtosis, 8th MUCET 2014, 10-11 November 2014, Melaka, Malaysia

c) **M.F. Ghazali,** G. Priyandoko, W.S.W. Hamat, T.W. Ching (2014) Plastic Pipe Crack Detection Using Ultrasonic Guided Wave Method, 8th MUCET 2014, 10-11 November 2014, Melaka, Malaysia

i) Human Capital Development

a) Ab Malik bin Awang Hamat@Mohamed: PhD on going
b) Nurul Fatiehah Adnan (Masters Student-completed)
c) Wan Sofian Wan Hamat @ Wan Safie (Masters Student- on going)

ii) Awards/ Others

a) Ainex 2015-Gold
b) Citrex 2015-Gold
c) ITEX 2015-Bronze
d) Citrex 2017-Silver

iii) Others

a) One patent submitted:

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APPENDIXES:

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Leak Detection in MDPE Gas Pipeline using Dual-Tree Complex Wavelet Transform

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ABSTRACT

Background: The pipeline system plays the important role in the industry and commonly use as media transport in the piping field on the land or on the sea as well. They are buried underground or situated in the wall of the buildings. The maintenance should be done properly to avoid any leakage to the surrounding. Therefore, the detection of the leak detection is the main investigation issue in order to get the fast and reliable leak detection method. Even though the reasons for these leaks are very well known, some of the current method is quite complicated and not precise. In addition, it is all about time consuming and cost of installment. In this paper, we proposed a leak detection method using acoustic. The chirp signal injected into the pipeline system and the estimation of the leak location from the delay time passing by the reflection in the pipeline if there have a leak. Using Dual Tree Complex Wavelet Transform, the signal filtered and decomposed into five levels. Then, the cepstrum analysis was used to detect the echoes for leak location estimation. When a leak occurred, the new peak shows and identified the presence in the pipeline network. The leak detected at a certain point and the error in this experiment is 0.62 % for leak location and 1.24 % for the outlet., which is nearly accurate to the original leak position. The DTCWT and ceptrum analysis could give acceptable result and possible to identify leaks that are difficult to find by other method.

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INTRODUCTION

In any application of engineering structure, pipelines are almost the main part to complete the media transport. The pipeline can be used to transfer air, water, oil and other fluids because of their cost and safety. Thus, as the main media transport they should be properly maintained, to avoid leaks. Usually, the leaks occur caused by damage from any accidents. The leaking and location of leaks needs to detect early. Monitoring any leaking is important in order to prevent any losses of fluid in term of cost. In addition, it can prevent any hazard to the surrounding. Different methods are used to investigate the leaking and their location. It includes visual inspections, acoustic emission, and dynamic pressure measurement. This paper proposed a signal processing method which is Dual Tree Complex Wavelet Transform (DTCWT). This signal processing tool analysis mainly decomposed the high frequency in low and high frequency. The cepstrum analysis used to find the echoes in the pipeline and as the main component to calculate the leak location with an equation.

Basic Principle Of Acoustic Leak Detection:

In air, sound travels by the compression and rarefaction of air molecules in the direction of travel. However, in solids, molecules can support vibrations in other directions, hence, a number of different types of sound waves are possible. When a leak or ruptures occurred in some places, there will be a change in the pressure balance which generated by friction of the gas or fluid with the wall of the pipeline. The reflection can be detected if there have blockage such as hole, junction, crack and ruptures. This reflection is known as a pressure wave that through inside the pipeline at the speed of sound (Lighthill, 1978). Figure 1 shows the concept of the reflection when a leak occurred. The time of reflected wave can be captured by generating pressure wave at certain location together with single remote sensor (Beck, Williamson, Sims, & Stanway, 2001). The low frequency can propagate for along the pipeline while the higher frequency will attenuate faster. Only the low frequency signal plays an important role in the gas pipeline leak detection. So, low frequency is the focus of this study.

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Leak Detection in Gas Pipeline using Hilbert-Huang Transform

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Keywords: Leak detection, gas pipeline, HHT, Ensemble Empirical Mode Decomposition

Abstract. This paper proposes a leak detection method using acoustic. The Hamming chirp signal injected into the pipeline system and the estimation of the leak location from the delay time passing by the reflection in the pipeline if there is a leak. By using Hilbert-Huang Transform (HHT), it can give a useful signal to verify the leak. HHT transforms Empirical Mode Decomposition (EMD)and Hilbert Spectrum analysis to perform time-frequency analysis. The leak location can be detected by multiplying by the speed of sound. This simple method gives accurate leak location and easy to implement.

Introduction

This project proposes a new criterion for new method of signal processing which is Hilbert-Huang Transform. This method actually was developed to study ocean wave because Hilbert-Huang Transform can analyse non-linear and non-stationary wave. The study on leak detection in acoustic before was done using cross-correlation analysis [1-3], cepstrum analysis [4-6], and also wavelet based-filtering [4, 5, 7, 8]. The experimental design was conducted using specific material of pipe. The several of parameter also give different results. The detection result can be simplified in term of time and location of the leak.

Wave Propagation in Pipeline

Current monitoring procedures require the multiple sensor such as pressure, flow meters or and valve sensor [8]. The passage of the wave can be detected by a change of pressure at a fixed point underneath of surface. So, the changes in the pipeline geometry such as valve, junction, blockage and leaks will create a reflection. This reflection is known as pressure wave that through inside the pipeline at the speed of sound [9]. The pressure wave is simulated using time domain based on transmission line modelling techniques [8, 10, 11]. Wave also can be detected by the motion of fluid particles. The time of reflected wave can be captured by generating pressure wave at certain location together with single remote sensor [1]. Speed is the distance travelled by wave per the time taken for the wave to travel to that distance. The length of the pipeline can be calculated by multiplying the time travel down in pipeline, t with speed of sound, a.

$$l = ta \tag{1}$$

The pipe is assumed rigid because flexible pipes will slow down the speed of the system. The pressure waves only travel in the fluid [1]. The leak location in the pipeline can be calculated using this formula:

$$x_{leak} = \frac{at_r}{2} \tag{2}$$

where:
x_{leak}= distance of the leak (m) from measuring section
t_r= time travelling (s)
a=speed of sound (m/s)

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IRREGULARITY DETECTION IN ARTIFICIAL SIGNAL USING TIME-FREQUENCY ANALYSIS

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ABSTRACT

A typical time signal contain overwhelming amounts of data and some of the signal components represent for irregularity such as crack and leak which greatly important to be identified precisely instead of using traditional method. The strategy can be done using signal processing method through high-quality time-frequency representation (TFR) for analysing such time dependent signals to accurately discover these superposition signal components. A few popular TFR methods such as wavelet transform analysis and relatively new, synchrosqueezed wavelet transform were applied in current study using artificial signal. From the result, both methods successfully discover an irregularity in the signal with different degree of accuracy and it is shown that synchrosqueezed wavelet transform provide the best and detailed time-frequency representation.

Keywords: irregularity, time-frequency analysis, synchrosqueezed wavelet transform.

INTRODUCTION

For frameworks of enthusiasm to researchers and engineers, examining the changing properties of a framework is normally performed by investigating signal information from the framework, instead of direct investigation of every part. Propelled time-frequency analysis give an arrangement of exploratory approaches for investigating changing frequency content in a signal, which can then be connected with anomalies forms in a framework.

Methods of signal transforming are major in comprehension signals from a wide mixed bag of fields. Raw time-amplitude signal that was transformed into frequency domain distinguishes the frequency substance of the signal, which is regularly more helpful than time space data for examination of dynamic properties. A fourier transform of a time period arrangement, for example a data signal of tremor record, contains data in regards to the frequency substance, however it can't resolve the accurate onset of changes in natural frequency, as time of transient data is carried just in the phase of the change.

Time-frequency analysis is a technique for changing from a time arrangement into a two-dimensional representation of frequency substance as for time. A TF analysis, by communicating frequency content at distinctive segments of a record, takes into consideration examination of developing signs. Numerous application or specialized works were directed utilizing TFR device for instance as a part of mechanical shortcoming analysis (Li *et al.*, 2013) and (Dong and Chen, 2012), speech (Tantibundhit *et al.*, 2010), biomedical (Abdulla and Wong, 2011) and (Musselman and Djurdjanovic, 2012), electronic framework (Castillejos *et al.*, 2012), seismic (Zhao *et al.*, 2014) and (Zheng *et al.*, 2013), geotechnical (Sudha *et al.*, 2009), etc., in which different TFR techniques have been employed to extract significant physical parameters from the raw signals.

In this paper we show the probability of the time frequency representation to identify inconsistency in artificial signal. First and foremost, utilizing a couple of TFR strategies, we extract the instantaneous frequency to make a comparison then determine the best representation in time-frequency plane. At that point we apply that TFR strategy to identify irregularity in artificial signal.

TIME-FREQUENCY ANALYSIS STRATEGY

Introduction of time-frequency analysis

Time-frequency representations are more generally utilized for non stationary signal examination which a robust strategy to transform a one-dimensional signal x(t) into a two-dimensional function of time and frequency, TFR (x;t, ω) to concentrate pertinent data. There exist numerous sorts of TFR algorithms which most of these instruments fall into two classifications: linear and quadratic techniques (Flandrin, 1999), each of which has its own particular qualities and shortcomings.

In the first method known as linear methods, the signal to be investigated is portrayed by its inner products with a preassigned group of layouts, created from one (or a couple of) essential format by basic operations. Cases are the windowed fourier transform, where the group of formats is produced by translating and modulating an essential window capacity. Another example is wavelet transform, where the layouts are gotten by translating and dilating the basic or so called mother wavelet.

The second strategy of TFR was quadratic method, which the signal is directly compared and evaluated without preceding a family of templates. Subsequently, a few components can have a crisper,

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Leak detection in gas pipeline by acoustic and signal processing – A review

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Abstract. The pipeline system is the most important part in media transport in order to deliver fluid to another station. The weak maintenance and poor safety will contribute to financial losses in term of fluid waste and environmental impacts. There are many classifications of techniques to make it easier to show their specific method and application. This paper's discussion about gas leak detection in pipeline system using acoustic method will be presented in this paper. The wave propagation in the pipeline is a key parameter in acoustic method when the leak occurs and the pressure balance of the pipe will generated by the friction between wall in the pipe. The signal processing is used to decompose the raw signal and show in time-frequency. Findings based on the acoustic method can be used for comparative study in the future. Acoustic signal and HHT is the best method to detect leak in gas pipelines. More experiments and simulation need to be carried out to get the fast result of leaking and estimation of their location.

1. Introduction

The pipelines operated for a number of years and tend to corrode. The slow process will lead to the big explosion if the gas is the main fluid filled in the pipeline system. The leak detection in gas pipeline is more difficult compared to water because of the poor signal noise to ratio (SNR). The large noise comes from gas flow itself. In addition, the geometrical features also one of the noise and make the leak detection in gas pipeline more complicated [1].

The leak detection techniques introduced in order to minimize the losses of medium transported by the pipeline. Three major categories can be divided to classify the technique. The first technique is automated detection, which can detect by monitoring system of pipeline network without human operator after the installation while, semi-automated detection need a certain input to perform some task in order to detect the leakage. The third category is manual detection, which is using the system and the device. It always needs to operate by human [2].

Classification of technique in order to detect leak in the pipeline also can be described as optical and non-optical methods as by Batzias [3]. Optical method more specific and sensitive compared to non-optical method, but their faces problem with the background noise. So, they need low reflection background material such as green grass, coarse snow, frost and sandy soil. But, direct and indirect leak detection also gives some idea in the classification of techniques. Direct technique normally uses visual inspection or device for detects the gas that escapes from pipeline network [4, 5].

Ultrasonic Guided Wave Method For Crack Detection In Buried Plastic Pipe

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Abstract. Plastic pipe are widely used in many fields for the fluid or gaseous product conveyance but basic components of a plastic material made it very sensitive to damage, which requires techniques for detecting damage reliable and efficient. Ultrasonic guided wave is a sensitive method based on propagation of low-frequency excitation in solid structures for damage detection. Ultrasonic guided wave method are performed to investigate the effect of crack to the frequency signal using Fast Fourier Transform (FFT) analysis. This paper researched to determine performance of ultrasonic guided wave method in order to detect crack in buried pipeline. It was found that for an uncrack pipe, FFT analysis shows one peak which is the operating frequency by the piezoelectric actuator itself while the FFT analysis for single cracked pipe shows two peak which is the operating frequency by the piezoelectric actuator itself and the resultant frequency from the crack. For multi cracked pipe, the frequency signal shows more than two peak depend the number of crack. The results presented here may facilitate improvements in the accuracy and precision of pipeline crack detection.

1 Introduction

Recent developments in pipelines systems have heightened the need for study about the pipe defect detection using ultrasonic guided wave method. In recent years, several studies have focused on defect detection in pipeline systems because it is very important used extensively all over the world to transport and distribute natural gas, crude oil, water, and other easy-flowing products. Indeed, in the process of continuous transportation, gas pipeline leakage cannot be avoided because of the corrosion of pipe walls [1], third-party interference [2], aging of the pipes [3], and so on. Therefore, leakage detection and localization is one of the paramount concerns of pipeline operators and researchers all over the world.

Many researchers have argued that Non-destructive testing (NDT) is a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage. NDT is a highly valuable technique that can save both money and time in product evaluation, troubleshooting, and research. Common NDT methods include ultrasonic, magnetic-particle, liquid penetrant, radiographic, remote visual inspection (RVI), eddy-current testing, and low coherence interferometry. According to K Haller (2007), damage can be monitored in many ways [4].

The choice of composite materials is no longer restricted to specific applications. In other fields, using these new materials as innovation tool and performance rising of their products such civil engineering. It is important first to have the best possible knowledge about these materials in somehow to monitor any changes in these properties and consequently their influence on the structure behavior [5, 6].

Plastic pipe is a good material because high resistance, light, cheap and longer life span. Therefore, plastic pipes usually are used to transport gas, water and chemicals. In general, plastic pipes are widely used over metal or concrete pipes. Due to the material being immune to water corrosion and highly resistant to fouling, it is also being considered as a replacement for stainless steel in safety-critical applications in nuclear power stations [7].

According to Carvalho et al. (2008), researchers have spent an ample amount of time, investigations and researched on non-destructive test techniques. As much as during the setting up phase during their useful life, these techniques are used as a method to asses engineering structures and system [8]. Crack inspection is a valuable non-destructive test (NDT) method in many industries. Crack inspection method is useful, which often exhibit complex geometries, are exposed to high thermal and mechanical loads and are expected to satisfy

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Detecting Leak in Gas Pipeline using Continuous Wavelet Transform and Kurtosis

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Abstract— **The detection of the leak detection is the main investigation issue in order to get the fast and reliable leak detection method. Even thought the reasons for these leaks are very well known, some of the current method is quite complicated and not precise. In addition, it is all about time consuming and cost of instalment. In this paper, we proposed a leak detection method using acoustic. The chirp signal injected into the pipeline system and the estimation of the leak detection from the delay time passing by the reflection of pressure wave in the pipeline if there have a leak. Using wavelet as the noise filtering, there can give a useful signal to verify the leak. Wavelet is the tool to de-noise the noise from the original signal and then tuned using maximum values of kurtosis. The main idea is the echoes detection of the pressure wave from the signal given by the original signal. Kurtosis plays the main role as the component to choose the filter parameter because of their nature to measure spikiness. The result shows that the highest value of kurtosis for the pipeline with leak is 6.465 while for the pipe without leak, the highest value for the kurtosis 5.3214.**

Index Terms—leak detection, gas pipeline, wavelet, kurtosis

I. INTRODUCTION

In any application of engineering structure, pipelines are almost the main part to complete the media transport. The pipeline can be used to transfer air, water, oil and other fluids because of their cost and safety. Thus, as the main media transport they should be properly maintained, to avoid leaks. Usually, the leaks occur caused by damage from nearby excavation equipment, accident, terrorism, earth movement or sabotage.

There are two categories which are liquid and gas. Both categories have similar problem associate even though physical properties are different. The leaking and location of leaks needs to detect early. Monitoring any leaking is important in order to prevent any losses of fluid in term of cost. In addition, it can prevent any hazard to the surrounding. Different methods are used to investigate the leaking and their location. It includes visual inspections, acoustic emission, and dynamic pressure measurement. The study on leak detection in acoustic before was done using cross-correlation analysis [1-3], cepstrum analysis [4-6], and also wavelet based-filtering [4, 5, 7, 8].

Transforming the time domain signal into frequency domain is really important in order to reveals the result of signal. Recently, many transforming method such as Fourier transform (FT), Short Time Fourier Transform (STFT), Continuous Wavelet transform (CWT), Discrete Wavelet transform (DWT), and Hilbert transform (HT).

This project proposes a new criterion for new method of signal processing which is Continuous Wavelet transform using Mexican hat as mother wavelet and tuned using maximum value of kurtosis based on experimental data with advance in chirp signal as input sound to the pipeline. The advantage of using CWT is because of the suitability signal processing tools for detection of singularities as discussed by Mallat [9] and Flandrin [10]. The details of algorithm for CWT are discussed in section IV. The reflection of the pressure wave can be detected if there have blockage such as hole, junction, crack and ruptures.

II. WAVE PROPAGATION IN PIPE

Current monitoring procedures require the multiple sensor such as pressure, flow meters or and valve sensor [8]. The passage of the wave can be detected by a change of pressure at a fixed point underneath of surface. So, the changes in the pipeline geometry such as valve, junction, blockage and leaks will create a reflection. This reflection is known as pressure wave that through inside the pipeline at the speed of sound [11]. The pressure wave is simulated using time domain based on transmission line modelling techniques [8, 12, 13]. Wave also can be detected by the motion of fluid particles. The time of reflected wave can be captured by generating pressure wave at certain location together with single remote sensor [1]. Speed is the distance travelled by wave per the time taken for the wave to travel to that distance. The length of the pipeline can be calculated by multiple of the time travel down in pipeline with speed of sound.

$$l = ta \tag{1}$$

Plastic Pipe Crack Detection Using Ultrasonic Guided Wave Method

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***Abstract*—The basic components of a plastic material made it very sensitive to damage, which requires techniques for detecting damage reliable and efficient. Ultrasonic guided wave is a sensitive method for damage detection. It is a method based on propagation of low-frequency excitation in solid structures. Experimental works are performed to investigate the effect of crack to the frequency signal. Ultrasonic guided wave tests are performed for the uncracked and cracked plastic pipes. The study involves the analysis of signal between the uncracked and cracked frequency graph. This paper focuses on the detection of damage by using ultrasonic guided wave method, whose main objective is to determine performance of ultrasonic guided wave method in order to detect crack in pipeline. The frequency signal for an uncracked pipe shows one peak which is the operating frequency by the piezoelectric actuator itself while the frequency signal for single cracked pipe shows two peak which is the operating frequency by the piezoelectric actuator itself and the resultant frequency from the crack. For multi cracked pipe, the frequency signal shows more than two peak depend the number of crack. The experimental results show that this method can enhance the accuracy and precision of pipeline crack detection.**

Keywords— Plastic pipe; crack; ultrasonic; guided wave method.

I. INTRODUCTION

Major advances have been made in recent years in pipeline technology. However, worldwide water distribution systems are mostly old. For example, there are over 54% of the pipes are older than 25 years and 24% are older than 50 years in many German systems. As pipes get older, the problems occurred increases in sewer pipes causing potential environmental problems, although in many cases these problems have yet to be quantified [1].

The choice of composite materials is no longer restricted to specific applications. In other fields, using these new materials as innovation tool and performance rising of their products such civil engineering. It is important first to have the best possible knowledge about these materials in somehow to monitor any changes in these properties and consequently their influence on the structure behavior [2,7].

Plastic pipe is a good material resistance light, cheap and longer life span. Therefore, plastic pipes usually are used to transport gas, water and chemicals. In general, plastic pipes are widely used over metal or concrete pipes. Due to the material being immune to water corrosion and highly resistant to fouling, it is also being considered as a replacement for stainless steel in safety-critical applications in nuclear power stations [3].

According to Carvalho et al. (2008), researchers have spent an ample amount of time, investigations and researched on non-destructive test techniques. As much as during the setting up phase during their useful life, these techniques are used as a method to asses engineering structures and system[4].

Crack inspection is a valuable non-destructive test (NDT) method in many industries. Crack inspection method is useful, which often exhibit complex geometries, are exposed to high thermal and mechanical loads and are expected to satisfy strict safety requirements. Lately, there is a need to expand a powerful crack defect detection methods [5].

Early detection of damage is not necessarily visible from the external face and even when it is the case of visual inspection does not realize its case state. In order of reliable and efficient use, these new materials, the development of a measurement system that can answer the following two questions of primary importance is required whether it could be measured directly in NDT and reliable mechanical properties of a composite structure. Is it possible to detect damage as quick as possible in order to monitor, evaluate and repair if necessary the structure [6].

II. EXPERIMENT SETUP

This experiment need to be carried out a few times to make sure a more accurate result is obtained. First, the experiment will be carried out on an undamaged plastic pipe. Data will be collected and analyzed. Next, the experiment will be carried out on a plastic pipe with a single crack. Last but not least, the experiment will be carried out on a plastic pipe with multi-cracks. All the data were collected and analyzed. From the data collected, we can compare the result of all the three specimen.

Piezoelectric stack actuator was used to excite the specimen. By placing the specimen on the foams and using a significantly smaller size of stack actuator, this is the best ompromise method for diagnosing defects. Nonlinear effects and noise effects from the attachment of the mechanical shaker or rigid supports can be prevented by using this method. A comparison was made between this method and the former method that using a mechanical shaker for the excitation. Although the maximum excitation level from the piezoelectric stack actuator is relatively lower than with the mechanical shaker, results from the latter method also showed a good signature of the sidebands effect against the defects [6,8].

The data collected will undergo analysis and converted into time base response in the DASYLab software. The data will also undergo amplification and filtering module. The amplification module is to amplify the data collected and filtering of the data is extremely vital in obtaining an accurate time base response graph. The plastic pipe will be attached the sensors and then it will be connected to a DAQ system. The DAQ system will be synchronized to the DASYLab software using the NI-DAQ software. The system will be configured to analyze the voltage as the sensor medium. The accelerometer will be controlled using the DASYLab software. After collecting the raw data, denoising were done by using MATLAB. Fig. 1 shows the experiment set up for this research.

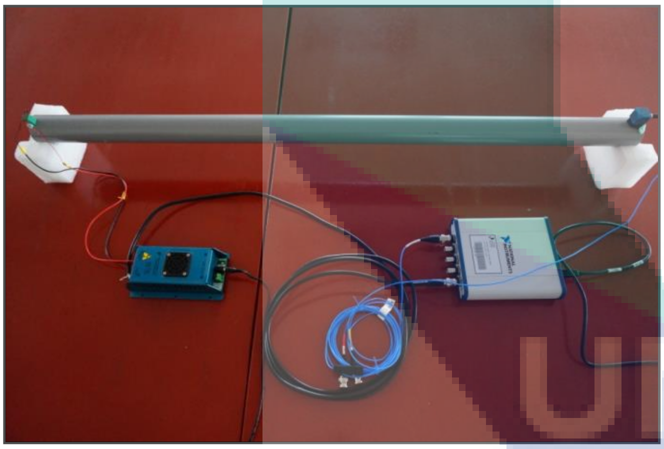

Fig. 1 : Full view for the experimental setup

III. ULTRASONIC GUIDED WAVE TESTING

The results were taken for the frequency of 3000 Hz, 6000 Hz and 9000 Hz. The distance between the sensor and actuator were placed at 30 cm, 60 cm and 90 cm. At each distance, the three frequency need to be tested. The raw data obtained from DASYLab can be denoised using MATLAB.

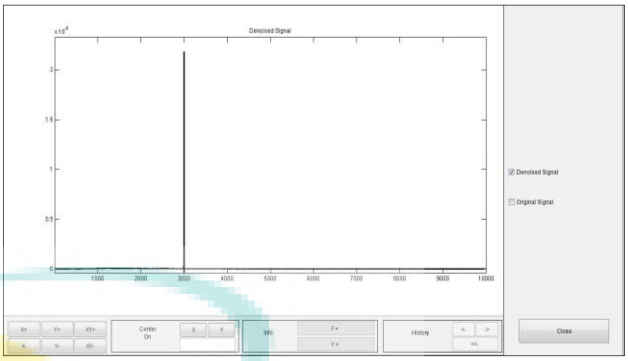

Fig. 2 : Frequency of 3000 Hz at 30 cm

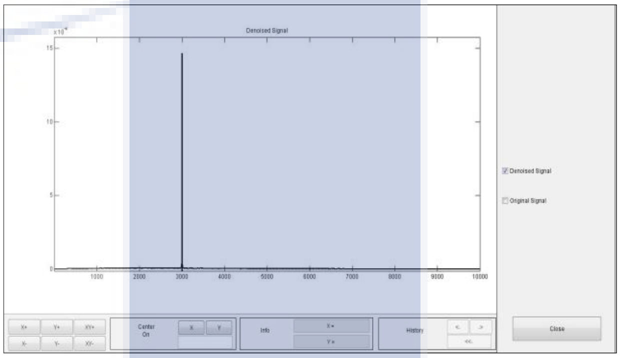

Fig. 3 : Frequency of 3000 Hz at 60 cm

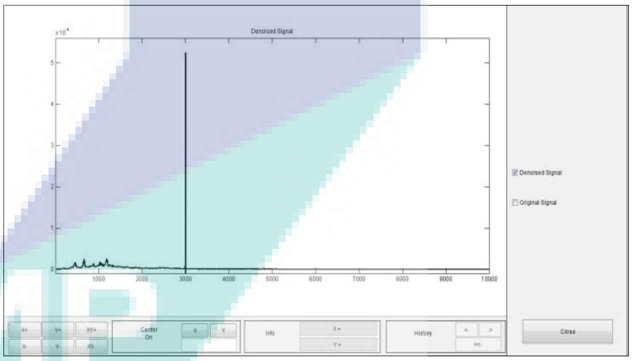

Fig. 4 : Frequency of 3000 Hz at 90 cm

Fig. 2, Fig. 3 and Fig. 4 show the frequency signal for 3000 Hz at distance 30 cm, 60 cm and 90 cm. The frequency signal amplitude are the highest at the distance 30 cm compare the distance 60 cm and 90 cm because the more capable of travelling at a short distance.

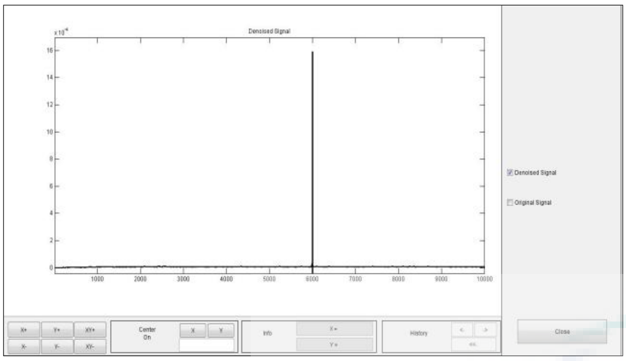

Fig. 5 : Frequency of 6000 Hz at 30 cm

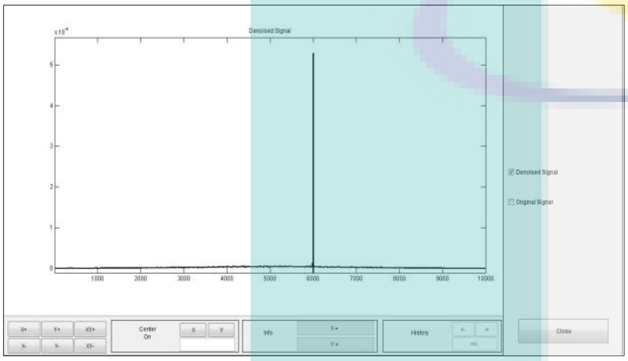

Fig. 6 : Frequency of 6000 Hz at 60 cm

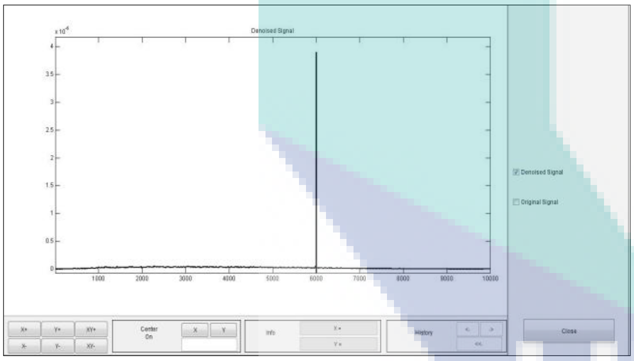

Fig. 7 : Frequency of 6000 Hz at 90 cm

Fig. 5, Fig. 6 and Fig. 7 show the frequency signal for 6000 Hz at different distance. The frequency signal amplitude are the highest at the distance 30 cm compare the distance 60 cm and 90 cm because the more capable of travelling at a short distance.

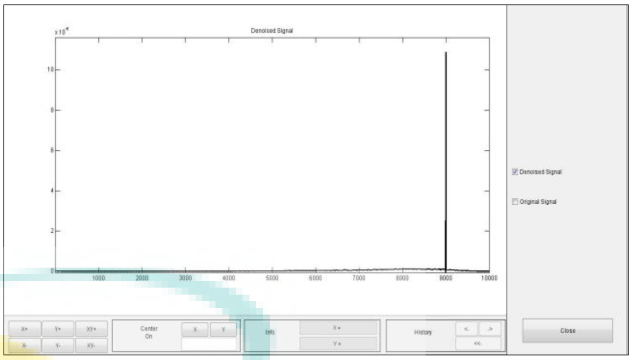

Fig. 8 : Frequency of 9000 Hz at 30 cm

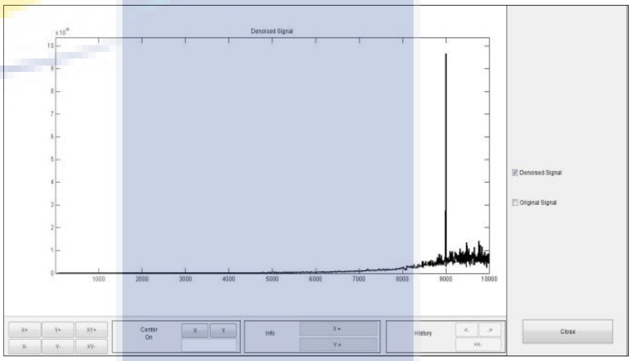

Fig. 9 : Frequency of 9000 Hz at 60 cm

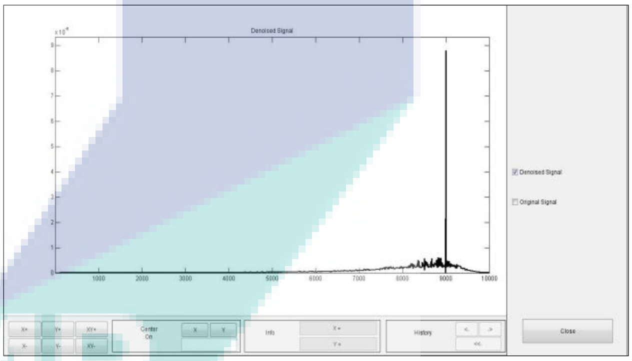

Fig. 10 : Frequency of 9000 Hz at 90 cm

Fig. 8, Fig. 9 and Fig. 10 show the frequency signal for 9000 Hz at different distance. The frequency signal amplitude are the highest at the distance 30 cm compare the distance 60 cm and 90 cm because the more capable of travelling at a short distance.

Table 1 shows the simplified frequency signal amplitude at different distance obtained from the frequency response graph.

TABLE I. FREQUENCY AMPLITUDE VALUE AT DIFFERENT DISTANCE

Frequency (Hz)	**Amplitude**		
	30 cm	***60 cm***	***90 cm***
3000	0.00200	0.00160	0.00050
6000	0.00160	0.00050	0.00004
9000	0.00011	0.00010	0.00009

From the trend of the graph, it could be clearly seen that the amplitude of the frequency response signal decreases as the distance between the piezoelectric actuator and accelerometer increases. For 3000 Hz, the frequency signal response amplitude is 0.00200 at 30 cm followed by 0.00160 at 60 cm and 0.00050 at 90 cm. For 6000 Hz, the frequency signal response amplitude is 0.00160 at 30 cm followed by 0.00050 at 60 cm and 0.00040 at 90 cm. For 9000 Hz, the frequency signal response amplitude is 0.00011 at 30 cm followed by 0.00010 at 60 cm and 0.00009 at 90 cm. All the frequencies show that that the frequency signal amplitude are the highest at the shortest distance. This shows that it is capable of travelling at a short distance.

In general, the frequency signal amplitude decreases in all samples due to the attenuation inside the testing medium as the distance from the source is increased too. It is clear that the attenuation increases with increasing distance. The transmitted signal is attenuated by the transmission medium which is the time required by the signal to reach the sensor point. This transmission makes some turbulence in the transmission medium and such turbulence may remain exist over this period of time. When transmission frequency increases, the transmission medium will contain effects of consecutive signals and constructive and destructive interferences would take place.

Accordingly, the accelerometer would receive transmitted signals at a higher frequency and if the accelerometer needs longer time to distinguish the received signals from each other, then higher frequency may cause destructive interference at the sensor, which in turn affects the final recorded signal amplitude. If the application requires using accelerometer in small samples with high accuracy, then working at small distances and low frequencies is the preferred. However, accelerometer can be used in case of large samples if the fine accuracy is not very important. Samples of chemicals, medicines and laboratory fluids can be considered as small samples. As well, crude oil pools in seas and drinking water reservoirs are large ones.

For cracked experimental investigation, the prepared plastic pipe was saw with an approximate thickness of 1 mm and 1 cm depth. That is to create a single cracked. For cracked testing the distance of the piezoelectric actuator and accelerometer is 90 cm. The distance of the cracked from the actuator was 15 cm. In this experiment, a frequency of 500 Hz was used. After the data was obtained, another 2 cracks were created which total of 3 cracks with the same thickness depth. The distance between the cracks are 15 cm. Same frequency was used for this testing. Joseph L. Rose; A Ultrasonic Guided Waves in Structural Health Monitoring supported this method.

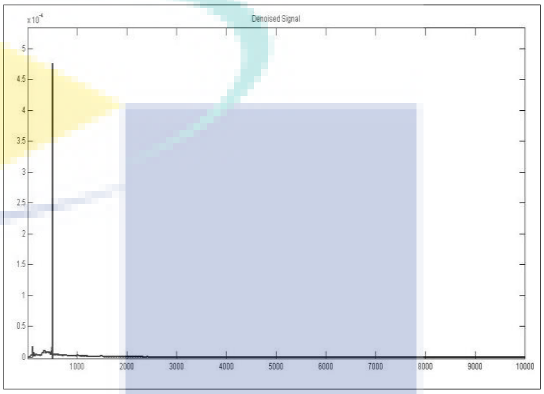

Fig. 11 : Frequency signal of uncracked pipe

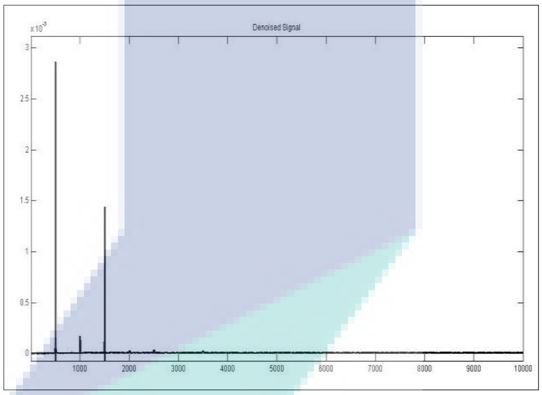

Fig. 12 : Frequency signal of single cracked pipe

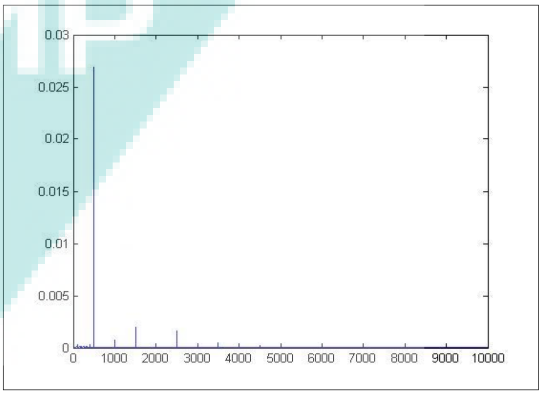

Fig. 13 : Frequency signal of multi cracked pipe

Fig. 11 shows the frequency signal for an uncracked pipe. From the frequency signal obtained, the data shows one peak which is the operating frequency by the piezoelectric actuator itself. Fig. 12 shows the frequency signal for single cracked pipe. From the frequency signal obtained, the data shows two peak which is the operating frequency by the piezoelectric actuator itself and the resultant frequency from the crack. Fig. 13 shows the frequency signal for multi cracked pipe. From the frequency signal obtained, the data shows three peaks which one peak is the operating frequency by the piezoelectric actuator itself and two a few peaks is the resultant frequency from the cracks.

Accelerometer has its own area of influence characterized by a sensing radius and the corresponding circle. Damage within the area of influence of the sensor is highly sensitive as it creates higher disturbances than the damage outside the area of influence. An exciting vibration at creates appreciable stress in the material affecting interfaces at all scales of damage. An ultrasound probe wave traveling through these interfaces is modulated due to vibration-induced changes in the interface condition and, as a result, additional spectral components appear at the frequencies. These new frequency components indicate that a flaw or crack is present.

IV. CONCLUSION

At the beginning of this research, the main objective is to design an experimental test rig for the plastic pipe crack detection. This objective has been successfully achieved as the experimental test rig is designed. Followed by the second objective, this project is aim to obtain the differences of frequency amplitude of the pipe different condition. With the verification of the experimental result, it is proved that as the distance of the piezoelectric sensor and accelerometer increases, the frequency signal amplitude decreases.

Another objective to carry this project is by means to determine the performance of ultrasonic guided wave method in order to detect crack in pipeline. For this objective, it is proven that the frequency signal peak increases with the number of cracks on the plastic pipe. In short, all the objectives and hypothesis are successfully achieved and proven. This project has been proven that ultrasonic guided wave method shows the differences of result in uncracked and cracked pipe. Therefore, it is firmly to conclude that ultrasonic guided wave method can be able to be used to detect crack in plastic pipes.

ACKNOWLEDGMENT

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Date: 16 November 2015

Our ref: UMP066/as
Your ref: UMP.05/28.13/3/(NA)

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COURIER

Dear Sirs:

NEW PATENT APPLICATION IN MALAYSIA – PI 2015002757 filed 16 November 2015
Applicant: UNIVERSITI MALAYSIA PAHANG
Inventors: MOHD FAIRUSHAM GHAZALI, NURUL FATIEHAH ADNAN and MOHD. FADHLAN MOHD YUSOF
Title: "ACOUSTIC SIGNAL PROCESSING METHOD FOR ACCURATE LEAK IDENTIFICATION IN GAS PIPELINES"

Thank you for your 27 May 2015 instructions on the above.

We are pleased to report that we have discussed the matter with the researchers, carried out the novelty searches, drafted the patent specification and submitted it for official filing with the Malaysian Intellectual Property Office (MYIPO).

We provide herewith the particulars of the patent application for your quick reference:

1. Title of patent application: "ACOUSTIC SIGNAL PROCESSING METHOD FOR ACCURATE LEAK IDENTIFICATION IN GAS PIPELINES"

2. UMP project title: Ledectsys-Leak Detection System

3. MYIPO official patent application no.: PI2015002757

4. MYIPO official application date: 16 November 2015

5. Inventor/s MOHD FAIRUSHAM GHAZALI, NURUL FATIEHAH ADNAN & MOHD. FADHLAN MOHD YUSOF

MYIPO will issue a Certificate of Filing (CF) along with preliminary report (to ascertain whether the patent application satisfies the formal requirements) in two to four weeks. We will forward the CF to you upon receipt along with a copy of the patent specification as filed.

We will inform you of any development in the patent application in due course. It has been a pleasure to serve you, and we look forward to working with you again.

Please let us know if you have any questions.

Thank you and best regards,

as
Ainoon Shabirin
Registered Patent Agent (Malaysia)

Encl (by courier)

SENARAI DAFTAR HARTA MODAL DI BAWAH DANA PENYELIDIKAN FUNDAMENTAL KEMENTERIAN PENDIDIKAN TINGGI (FRGS)

BIL	IPT	JENIS GERAN (FRGS/ERGS/LRGS/PRGS/NRGS/RAGS/RACE/TRGS)	FASA (CONTOH 2/2014)	TAJUK PROJEK PENYELIDIKAN	NAMA KETUA	NAMA ASET	BILANGAN UNIT	NO SIRI PENDAFTARAN	TARIKH PEROLEHAN	HARGA PEROLEHAN ASAL (RM)
1	UMP	RAGS(RDU130111)	1/2013	A new technique of leak detection in a gas pipeline network based on time reversal method and non linear acoustic	Ir Dr Mohd Fairusham Ghazali	Microphone	1	FKM1000-PB105(R)-1308-0001-00001		4944
2						Pressure sensor	1	FKM1000-PB105(R)-1308-0001-00002		3840
3						CompactDAQ Chassis	1	FKM1000-PB105(R)-1604-0001-00001		8127
4										
5										