International Journal of
Innovation in Mechanical Engineering & Advanced Materials (IJIMEAM)
https://publikasi.mercubuana.ac.id/index.php/ijimeam
Vol.3 (No.2). 2021. pp. 58-64
Published online: Sept. 4, 2021
ISSN: 2477-541X

LEAKAGE DETECTION ON THE GALVANIZED IRON PIPELINE USING EMPIRICAL MODE DECOMPOSITION AND HILBERT-HUANG TRANSFORM

M. F. Ghazali[1] and G. Priyandoko[2]*

[1]Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, MALAYSIA
[2]Department of Electrical Engineering, Faculty of Engineering, University of Widyagama, INDONESIA

Abstract
Pipeline networks are one of the most important transportation for gas, oil and water. Leakage in pipelines results in extensive financial loss. To avoid this situation, an algorithm based on the Empirical Mode Decomposition method (EMD) and Hilbert-Huang Transform (HHT) is presented in the research. The objectives of this research to detect pipelines leakage by using EMD method and to locate the location of the leak by using HHT method. The research focuses on the Galvanized Iron (GI) pipe and which the acoustic signal measured by the microphone which act as a sensor is collected by using DASYLab software at frequency of 100 Hz and 500 Hz. It is shown that GI pipe and frequency of 500 Hz produce more accurate results based on the analysis process.

Keywords: Pipeline, Galvanized Iron, Leakage, Empirical Mode Decomposition, Hilbert-Huang Transform

*Corresponding author: Tel. +62 341 411291
E-mail address: gigih@widyagama.ac.id

1. Introduction

Pipeline networks are one of the most important transportation for gas, oil and water. It is the most convenient and are used extensively all over the world. It is the lifeline of the current industry and the national economy. However, from time to time, gas leakages in pipelines cannot be avoided due to aging, third-party damage, corrosion, excessive pressure resulting from operational error, natural disasters and impact forces of construction equipment [1–2].

Leaks in pipelines result in extensive financial loss to the industry besides affecting public health. Other than that, gas leaks can also cause industrial hazards and causes environmental destruction. Leakage detection and localization are very important to ensure safe operation. Therefore, various monitoring systems such as acoustic leak detection, vapor sampling method, mass balance method, statistical method and cable sensor method has been developed to prevent further loss and public risk [3–5].

A detectable physical quantity or impulse by which messages or information can be transmitted is called signal. It is the vehicle that carries information from one time and place to another. Using dynamics signal is tough since non-deterministic type of signal normally occurs in real application. Surrounding which were mixes together with the real signal and affecting the final result is one of the factors involved on real application. To solve this matter, by its statistical behavior and through any pattern recognition method, the hidden information inside the random signal was understood. The signal needs to be transformed in some cases in order to reveal some hidden information. Thus, the transformation method such as Wavelet Transform, Fast Fourier Transform, Short-Time Fourier Transform, Hilbert Huang Transform and many more comes for this purpose and these approaches applied in frequency-domain and time-frequency analysis [6–11].

A method of breaking down a signal without leaving the time domain is called Empirical Mode Decomposition (EMD). EMD decomposes the data into a number of intrinsic mode function (IMF) components, thus expanding the data on a basic derived from it [12-13]. This new non-linear technique has been pioneered by N. E. Huang. EMD is a kind of numerical algorithm for decomposition of time signal on the scale of the frequency, and the components will be different scales of fluctuation signal or trend by gradually decomposing out [14].

Differ from the Fourier transform which takes a time-domain signal and moves it into the frequency domain, the Hilbert transform produces another tie-domain signal. Hilbert transform is a relationship between real and imaginary components of the Fourier transform. HHT is used to analyses non-linear and non-stationary signals. HHT consists of empirical mode decomposition (EMD) and Hilbert spectral analysis. The HHT decomposes any given signal into

Vol.3 (No.2). 2021. pp. 58-64
Published online: Sept. 4, 2021
ISSN: 2477-541X

a small number of Intrinsic Mode Functions (IMF) and the Hilbert spectrum will be used to represent the full energy frequency-time distribution of data. With the adaptive nature behavior of EMD, it can be an ideal method to analyses non-linear and non-stationary signals [4,12,15]. The objectives of the research to identify the leakage in pipeline using the Empirical Mode Decomposition (EMD) and the Hilbert-Huang Transform (HHT).

2. Empirical Mode Decomposition

Since 2004, EMD has been widely used to address issues such as system identification, damage detection, structural health monitoring, and condition assessment of structures [13]. In most research, EMD was used to test a single measurement. The EMD is a new signal decomposition technique that can be used in a variety of fields. The latter is capable of processing non-linear and non-stationary data effectively [14]. EMD has shown the instant, severity and several damaged occurrences which make EMD a suitable tool for SHM of the real structures could be accurately recognized.

The EMD method decomposes a multi-component signal into IMFs, which are single-frequency elements. An IMF is a function that meets any of the following criteria [12, 14-15]:

a. In the entire data set, the number of extrema and zero-crossings must be equal or vary by no more than one,
b. At any point, the mean value of the envelope denoted by the local maxima and local minima must be zero.

The procedure of extracting an IMF is called sifting. Suppose $y(t)$ is the signal to be decomposed, the main steps of EMD are as follows:

a. Connect all the local maxima and minima by using a cubic spline to extract the upper and lower envelopes.
b. Find the mean of upper and lower envelopes, which is designated as $m_1(t)$.
c. Determine the difference between the signal $y(t)$ and the mean $m_1(t)$, $i_1(t) = y(t) - m_1(t)$ which could be the first IMF.
d. Check if $i_1(t)$ meets the two conditions of IMF that are mentioned above. If $i_1(t)$ meets both conditions to be an IMF, then $i_1(t)$ is the first IMF of the original signal $y(t)$.
e. If $i_1(t)$ does not meet the requirements of IMF, the sifting process will be repeated by treating the $i_1(t)$ as original signal until it meets the two conditions of the IMF.
f. The original signal is subtracted from the IMF, and the sifting process is repeated to decompose the data into n IMFs.

In addition, the EMD algorithm generates IMFs that are locally orthogonal. Since adjacent IMFs can have similar frequencies at different time points, global orthogonality is not guaranteed.

3. Hilbert-Huang Transform

After extracting all IMFs, it can be further analyzed using the Hilbert transform method [15]. The Hilbert transform equation is,

$$H\{x_i(t)\} = \frac{1}{\pi} P\left\{\int_{-\infty}^{\infty} \frac{x_i(\tau)}{(t-\tau)} d\tau\right\} \quad (1)$$

An analytical signal $z_i(t)$ can be described in this way.

$$z_i(t) = x_i(t) + iH\{x_i(t)\} \quad (2)$$

$$z_i(t) = a_i(t) exp(i\theta_i(t)) \quad (3)$$

with amplitude $a_i(t)$ and instantaneous phase $\theta_i(t)$ given by,

$$a_i(t) = \sqrt{x_i^2(t) + H\{x_i(t)\}^2} \quad (4)$$

$$\theta_i(t) = arctan\left(\frac{H\{x_i(t)\}}{x_i(t)}\right) \quad (5)$$

As a result, every non-stationary and non-linear time series must be decomposed into stationary IMFs using an EMD. A Hilbert-Huang Transform is a mixture of EMD and the Hilbert transform.

4. Methodology

4.1 Materials

The type of pipe's material has been chosen for this research which is Galvanized Iron (GI). Galvanized iron is used widely for pipes, wire, and sheeting and also for home supplies. GI pipe are cheap and easy to join. Hardware used in this research are microphone, speaker and National Instruments. Software used in this research are NI Measurement & Automation Explorer (MAX), DASYLab and MATLAB.

4.2 Experiment

The test rig includes the three different types of materials which are GI pipes, microphone, speaker, National Instruments and Laptop. Figs. 1–2 below shows the test rig setup when pipe is used and schematic diagram of the test rig, respectively. The setup of the test rig can be seen clearly based on the schematic diagram above. For all the three materials, the speaker is connected to the laptop and is placed at the inlet of the pipe. The microphone is placed at 1 m from the inlet of the pipe and is connected to the National Instruments. Hole type of leak of about 1 cm is located at the distance of 4 m from the inlet of the pipe. The outlet of the pipe is at the distance of 6m from the inlet of GI pipe while at the distance of 5.8

International Journal of
Innovation in Mechanical Engineering & Advanced Materials (IJIMEAM)
https://publikasi.mercubuana.ac.id/index.php/ijimeam
Vol.3 (No.2). 2021. pp. 58-64
Published online: Sept. 4, 2021
ISSN: 2477-541X

m from the inlet of the pipe.

Experimental procedures in conducting this research are as follow:

a. The leak on the GI pipe is closed.
b. Sine wave sound is injected into the GI pipe through the speaker connected at the inlet of the pipe.
c. The acoustic signal measured by the microphone which act as a sensor is collected by using DASYLab software at frequency of 100 Hz and 500 Hz.
d. The data that have been collected is analyzed by using MATLAB software.

Fig. 1. The test rig for pipe leak detection

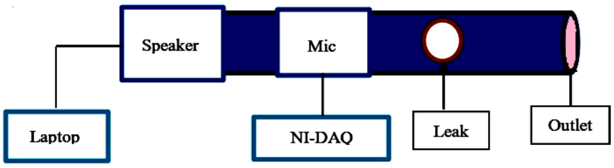

Fig. 2. Schematic diagram of the test rig

5. Results and Discussion

Raw signal data for all materials at both 100 Hz and 500 Hz of frequency are shown in Figs. 3–6. The two frequencies were chosen, because the frequency of leak signals is usually higher than 200 Hz [16–17]. One signal is selected which has a frequency below 200 Hz and another has a frequency above 200 Hz. The raw data is taken when there is no leak on the pipe and when there is a leak on the pipe.

From raw signals in Figs. 3–6, when there is no leak, it can be seen that the signal fluctuates at the distance of about 1.7 m and 6 m for the GI Pipe. When there is a leak, the raw signal fluctuates around the distance of 3 to 4 m. On the other hand, it can be seen that the raw signal when the frequency is at 500 Hz is smoother than the raw signal when the frequency is at 100 Hz. However, it is difficult to detect and locate the leakage by using these raw signals. because the signals are almost the same shape; it is difficult to determine the occurrence of leaks and where the pipe leaks occur. Therefore, thorough analysis needs to be done in order to detect and locate the leakage. Such that, the raw signals received need to be decomposed. In order to decompose all the signals, EMD analysis is used. EMD will decompose all the signals into nine IMF. After the decomposition process, the IMF will be further analyzed by using HHT.

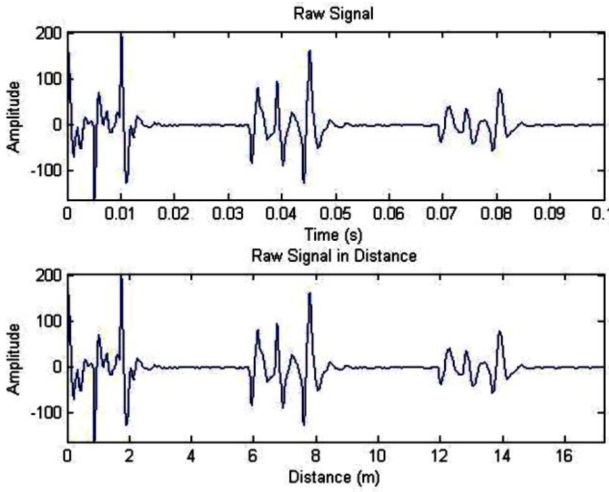

Fig. 3. Raw Data Signal of GI Pipe at Frequency of 100 Hz (No Leak)

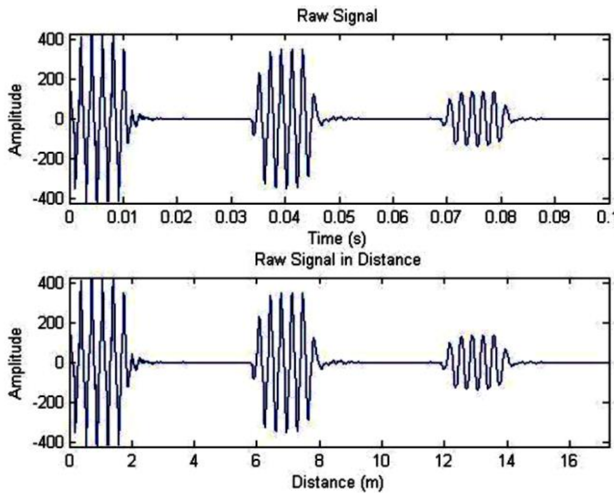

Fig. 4. Raw Data Signal of GI Pipe at Frequency of 500 Hz (No Leak)

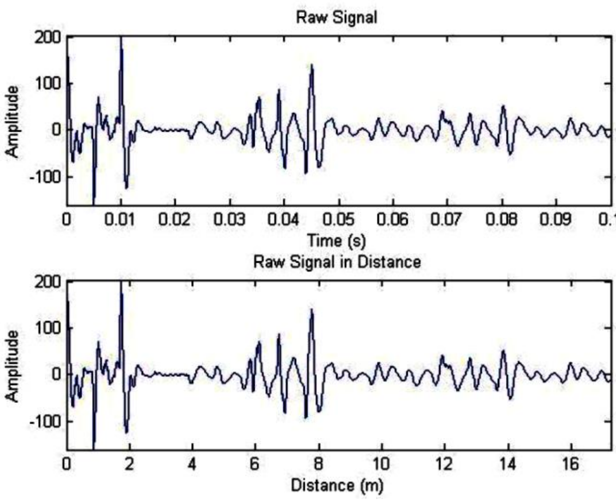

Fig. 5. Raw Data Signal of GI Pipe at Frequency of 100 Hz

Vol.3 (No.2). 2021. pp. 58-64
Published online: Sept. 4, 2021
ISSN: 2477-541X

(with Leak)

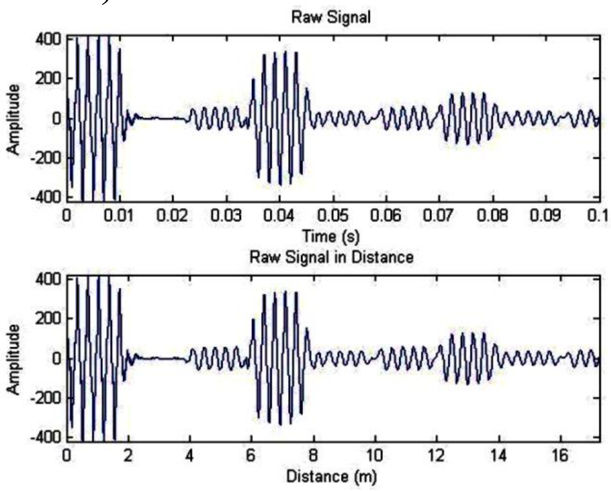

Fig. 6. Raw Data Signal of GI Pipe at Frequency of 500 Hz (with Leak)

IMF data for GI pipe at both 100 Hz and 500 Hz of frequency it can be seen in Figure 7–9. The IMF data is taken when there is no leak on the pipes and when there is a leak on the pipe.

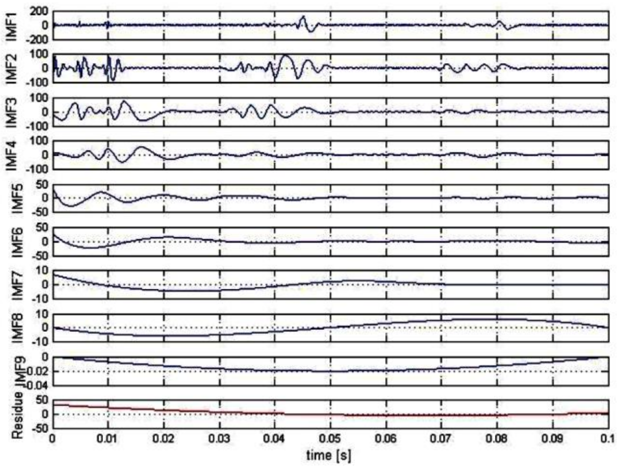

Fig. 7. The nine IMF components for GI Pipe at Frequency of 100 Hz (No Leak)

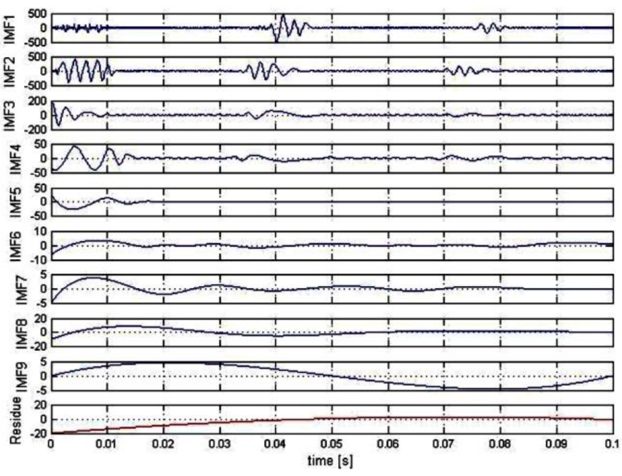

Fig. 8. The nine IMF components for GI Pipe at Frequency of 500 Hz (No Leak)

The first component of the IMF shows the time/pressure response while the last one indicates the residual of the signal. The signal is then analyzed by using HHT. Hilbert Spectrum (HS) for all materials at both 100 and 500 Hz of frequency will be shown below. The HS is taken when there is no leak on the pipes and when there is a leak on the pipes. The signals will be decomposed from high frequency to low frequency.

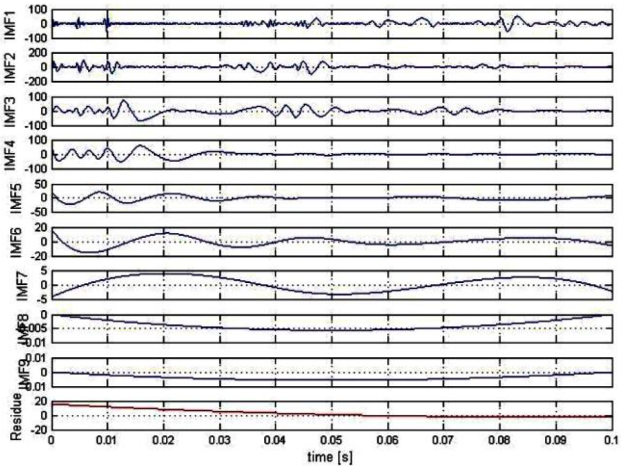

Fig. 9. The nine IMF components for GI Pipe at Frequency of 100 Hz (with Leak)

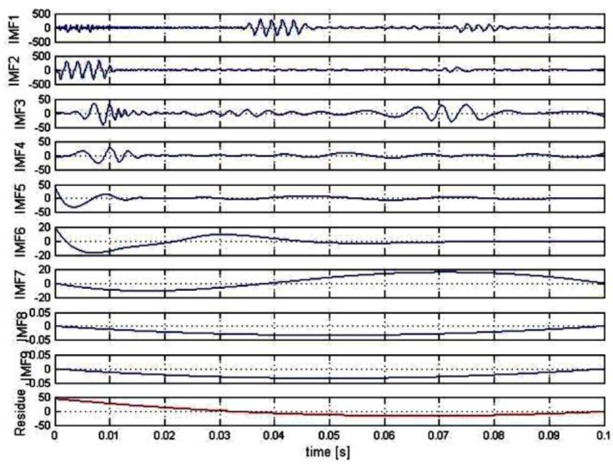

Fig. 9. The nine IMF components for GI Pipe at Frequency of 500 Hz (with Leak)

All the figures above shows the Hilbert Spectrum (HS) for GI pipe at two different frequency which are 100 and 500 Hz and at two different conditions which are with and without leak. From the spectrums when there is no leak, it can be seen that there is a spike at the distance of 1.7 m and 6 m for GI Pipe. It can be seen that there is a spike at the distance of 1.7 m and 5.8 m. When there is a leak, there is a spike at the distance of 4 m for GI pipe. The spike can be easily seen when the frequency is at 500 Hz compared to

Vol.3 (No.2). 2021. pp. 58-64
Published online: Sept. 4, 2021
ISSN: 2477-541X

when the frequency is at 100Hz.

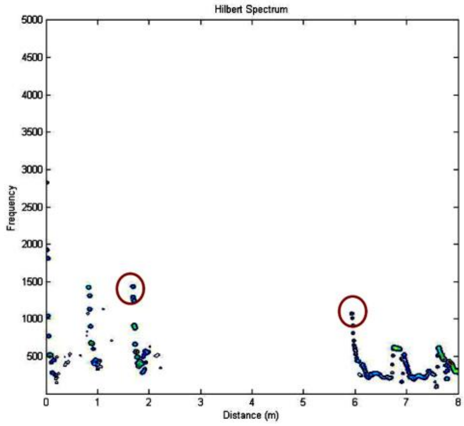

Fig. 10. Hilbert Spectrum (HS) of GI Pipe at Frequency of 100 Hz (No Leak)

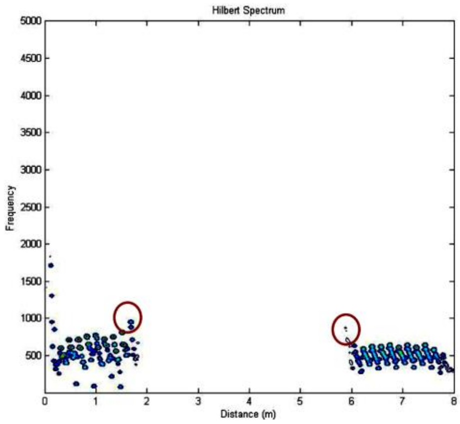

Fig. 11. Hilbert Spectrum (HS) of GI Pipe at Frequency of 500 Hz (No Leak)

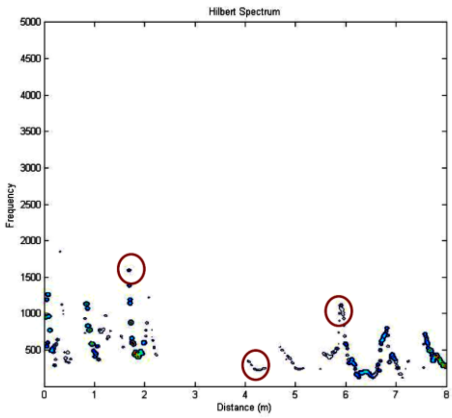

Fig. 12. Hilbert Spectrum (HS) of GI Pipe at Frequency of 100 Hz (with Leak)

Tables 1–2 below shows the analysed distance, measured distance and percentage error for GI pipe at both 100 and 500 Hz. All the data are obtained from the Hilbert Spectrum obtained in the analysis process.

As can be seen from all the graphs above, for GI pipe, at the distance of about 1.7 m, there is a spike detected since that is the distance of the sound injected. This can be proved by using the calculation below: Sound injected at = 0.01 s, Speed of sound = 345 m/s. Distance = (0.01x345)/2 = 1.725 m. The spikes that can be seen at the distance of 6 m for GI pipe and GI pipes are 6m and the length of the PVC pipe is 5.8 m. The spikes that can be seen at the distance of 4 m for all the three pipes are because of the leak which is a hole type of leak. The percentage error between the analyzed distance and measured distance when using GI pipe is also small. This is because, GI pipe have hard body pipe. As we know, soft surfaces will absorb sound faster than hard surfaces. Therefore, the sound absorption process that occur on the body of the GI pipe is slow. This is the reason why it is easier to detect the spike at the Hilbert Spectrum of the GI pipe. On the other hand, the results can also be more clearly seen when the frequency is at 500 Hz compared to when the frequency is at 100 Hz. The frequency of the air inside the pipeline system is about 100 to 500 Hz. Therefore, the frequency chosen must be between this range, due to limitation hardware capability for this research. Choosing smaller frequency or larger frequency will cause difficulties in reading the data from the Hilbert Spectrum obtained [2,16-17].

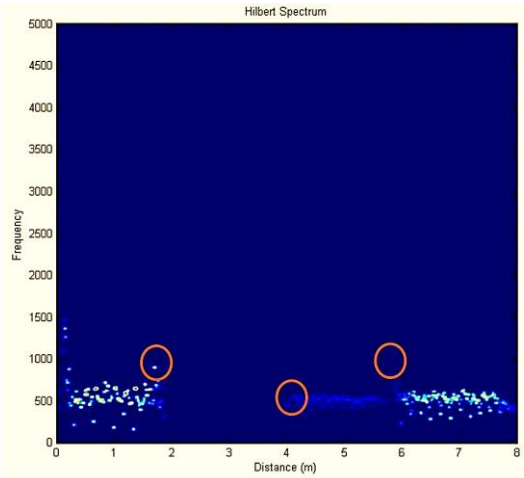

Fig. 13. Hilbert Spectrum (HS) of GI Pipe at Frequency of 500 Hz (with Leak)

Table 1. Results for GI Pipe at 100 Hz

Test	Analyzed Distance (m)		Measured Distance (m)		Error (%)	
	Leak	Outlet	Leak	Outlet	Leak	Outlet
1	4.08	5.91	4.00	6.00	2.00	1.50
2	4.06	5.96	4.00	6.00	1.50	0.67
3	4.02	5.94	4.00	6.00	0.50	1.00

Vol.3 (No.2). 2021. pp. 58-64
Published online: Sept. 4, 2021
ISSN: 2477-541X

Table 2. Results for GI Pipe at 500 Hz

Test	Analyzed Distance (m)		Measured Distance (m)		Error (%)	
	Leak	Outlet	Leak	Outlet	Leak	Outlet
1	3.99	6.08	4.00	6.00	0.25	1.33
2	3.97	6.03	4.00	6.00	0.75	0.50
3	3.99	5.98	4.00	6.00	0.25	0.33

6. Conclusions

This research focuses on leakage detection in pipelines and on how to locate the identified leakage. In order to detect the leakage, sine wave sound is injected into the pipe and the signal received will be recorded using the DASYLab software. The signal is then decomposed into IMF by using EMD analysis. The decompose IMF is then being analyzed by using HHT analysis in order to locate the leakage. Both analysis process is done using MATLAB software. It is proved that leakage in pipeline system can be detected. During this study, the material of pipes which is GI. This research also focuses on the difference between the Hilbert Spectrum obtained when the frequency is at 100 Hz and 500 Hz. It is clearly proved that when the frequency is at 500 Hz, the Hilbert Spectrum obtained can be read easily.

References

[1] S. Li, Y. Wen, P. Li, J. Yang, X. Dong, and Y. Mu, "Leak Location in Gas Pipelines using Cross-Time–Frequency Spectrum of Leakage-Induced Acoustic Vibrations," *Journal of Sound and Vibration*, vol. 333, no. 17, pp. 3889–3903, 2014.

[2] Q. Xiao, J. Li, J. Sun, H. Feng, and S. Jin, "Natural-Gas Pipeline Leak Location using Variational Mode Decomposition Analysis and Cross-Time Frequency Spectrum," *Measurement*, vol. 124, pp. 163–172, 2018.

[3] L. Boaz, S. Kaijage, and R. Sinde, "An Overview of Pipeline Leak Detection and Location Systems," in *Proceedings of the 2nd Pan African International Conference on Science, Computing and Telecommunications (PACT 2014)*, Arusha, Tanzania, 2014, pp. 133–137.

[4] M. L. Tao, W. Zhao, L. Peng, and L. Shurong, "Applications of an Improved EMD Method in Signal Denoising of Oil Pipeline," in *2017 29th Chinese Control and Decision Conference (CCDC)*, Chongqing, China, 2017, pp. 3986–3991.

[5] S. Pan, Z. Xu, D. Li, and D. Lu, "Research on Detection and Location of Fluid-Filled Pipeline Leakage Based on Acoustic Emission Technology," *Sensors*, vol. 18, no. 11, p. 3628, 2018.

[6] M. Ghazali, S. Beck, J. Shucksmith, J. Boxall, and W. Staszewski, "Comparative Study of Instantaneous Frequency Based Methods for Leak Detection in Pipeline Networks," *Mechanical Systems and Signal Processing*, vol. 29, pp. 187–200, 2012.

[7] D. Zaman, M. K. Tiwari, A. K. Gupta, and D. Sen, "A Review of Leakage Detection Strategies for Pressurised Pipeline in Steady-state," *Engineering Failure Analysis*, vol. 109, p. 104264, 2020.

[8] S. El-Zahab and T. Zayed, "Leak Detection in Water Distribution Networks: an Introductory Overview," *Smart Water*, vol. 4, no. 1, pp. 1–23, 2019.

[9] R. Ramadevi, J. Jaiganesh, and N. Krishnamoorthy, "Leak Detection Methods—a Technical Review," in *International Conference on Communications and Cyber Physical Engineering 2018*, 2018, pp. 125–139.

[10] A. Gupta and K. Kulat, "A Selective Literature Review on Leak Management Techniques for Water Distribution System," *Water resources management*, vol. 32, no. 10, pp. 3247–3269, 2018.

[11] M. I. M. Ismail *et al.*, "A Review of Vibration Detection Methods using Accelerometer Sensors for Water Pipeline Leakage," *IEEE access*, vol. 7, pp. 51965–51981, 2019.

[12] H. Bakhti, M. Bentoumi, A. Harrag, and K. El-Hadi, "Experimental Validation of Hybrid EMD-Correlation Acoustic Digital Leaks Detector in Water Distribution Network System," *Instrumentation Mesure Métrologie*, vol. 18, no. 6, pp. 535–545, 2019.

[13] M. Barbosh, P. Singh, and A. Sadhu, "Empirical Mode Decomposition and Its Variants: A Review with Applications in Structural Health Monitoring," *Smart Materials and Structures*, vol. 29, no. 9, p. 093001, 2020.

[14] N. E. Huang, "New Method for Nonlinear and Nonstationary Time Series Analysis: Empirical Mode Decomposition and Hilbert Spectral Analysis," in *Proc. SPIE 4056, Wavelet Applications VII*, 2000, vol. 4056, pp. 197–209.

[15] N. E. Huang *et al.*, "The Empirical Mode Decomposition and The Hilbert Spectrum for Nonlinear and Non-Stationary Time Series Analysis," *Proceedings of the Royal Society of London. Series A: mathematical, physical and engineering sciences*, vol. 454, no. 1971, pp. 903–995, 1998.

[16] C. Guo, Y. Wen, P. Li, and J. Wen, "Adaptive Noise Cancellation Based on EMD in Water-

Vol.3 (No.2). 2021. pp. 58-64
Published online: Sept. 4, 2021
ISSN: 2477-541X

Supply Pipeline Leak Detection," *Measurement*, vol. 79, pp. 188–197, 2016.
[17] Z. Jian-li and G. Wei-xing, "Study on The Characteristics of The Leakage Acoustic Emission in Cast Iron Pipe by Experiment," 2011, pp. 122–125.