Effects of Variations in Pipe Leakage Diameter and Pipe Leakage Distance to the FFT Diagrams

Andrey Putra Wijayanto* and I Made Miasa

Department of Mechanical and Industry Engineering, Engineering Faculty, Universitas Gadjah Mada, Grafika Street No. 2, Yogyakarta 55281, Indonesia

*Corresponding author’s email: andrey.p.wijayanto@gmail.com

Abstract. A method for detecting leaks in plastic water supply pipes through analysis of the pipe’s surface vibration using an accelerometer is proposed. Various diameter of leaks and distance of leaks are examined. The method involves identification of the changes vibration spectrum in Fast Fourier Transform (FFT) diagram caused on the pipe by various leak scenario. It is showing that FFT diagram on pipe small leak is difficult to be distinguished with FFT diagram with pipe no leak scenario. However, pipe big leak shows narrow frequency dominant in FFT diagram with high values on acceleration. The further leakage points from accelerometer, trend of frequency dominant in the FFT diagram is getting lower.

1. Introduction

Fluid transportation using piping systems is an important facility of the infrastructure in the modern society. The Indonesian State Water Company (PDAM) is one of the regional-owned business units, which is operated in the distribution of fresh water to public using water pipeline network in Indonesia. The main factors affecting water distribution company performance is the level of water loss. The non-billed water not only causes financial losses, but also causes water volume and pressure to flow into house connections to be reduced. In order to prevent or even more leakage of water pipelines, a more reliable and efficient way to monitor the pipelines is required.

Leakage in water distribution pipes is divided into three categories: reported, unreported and background. Reported and unreported leaks are defined as major bursts or leaks caused by structural failures of the pipe. This type of leakage can be detected by changes in pressure along the pipe. However, background leak is outflows originating from small cracks, holes or joints along the pipe and cannot be detected with decreasing pipe pressure [1].

Background leak detection in pressurized plastic pipes can be obtained by vibration analysis using hydrophones, acoustic emission sensors and accelerometers attached to the pipe wall [2, 3, 4]. Accelerometer attached to a plastic pipe in the upstream part of the flow shows a change in frequency when the pipe is leaking which is displayed on the Fast Fourier Transform (FFT) diagram, Power Spectral Density (PSD), Cross Power Spectral Density (CPSD) and Wavelet Transform for analysis [5].

Current detection leakage point in plastic pipes could be carried out with the cross-correlation method by measuring time delay that receives by the accelerometer that are installed at upstream and downstream of flow [6]. Furthermore, by removing the additional phase shifts in the system that is caused by resonances the shape of the cross-correlation function can be improved to make it easier to determine the time delay estimate (TDE) [7].
This research will focus on how to identify pipe leaks by comparing the vibration spectrum before and after the leak, how to distinguish vibration spectrum in types of leakage by comparing the effects of small and large leaks and how to determine the point of leakage of the pipe by identifying the vibration spectrum trends by varying the distance of the leak points.

2. Theory Approach

2.1. Pipe Leak Detection Using Acoustic Method

Basically, the principle of acoustic-based leak detection is when a leak occurs, the leak will produce acoustic noise around the leak point. An accelerometer mounted on the pipe wall to record the baseline profile of the vibration is produced by the fluid flow in the pipe. When a leak occurs, a low-frequency acoustic signal will be detected and identified by the accelerometer. If there is a change in the vibration profile from the baseline conditions, it can be concluded that there is a leak in the pipe [8].

Pipeline leak detection using a high-sensitivity accelerometer can cause the long duration of the leak to be detected. Vibration caused by leaking on the pipe surface has a higher acceleration value compared to other sources of vibration. Leakage of water flowing in the pipeline cannot be immediately detected with differences in amplitude acceleration due to vibrations generated from the flow of water negating vibrations from leakage phenomena. However, leakage can still be detected by frequency domain analysis.

Research on plastic pipes leaks detection in water distribution networks is based on the computation of kurtosis from the normalization of autocorrelation in vibro-acoustic signals by measuring the vibrational spectrum and monitoring the induction pressure from the leakage point. Experimental research yields effectiveness when monitoring longitudinal vibrations from pipe walls. The benefit of using this method is being able to show high sensitivity to leakage according to the expected range [9].

Vibro-acoustic emission signal process to quantify leakage flow rates in water distribution plastic pipe was investigated by placing accelerometers or hydrophones in both inlet and outlet pipes by varying the environmental media of water leakage. This study found a strong correlation between leakage flow rates and Root Mean Square (RMS) signals which made it possible to model the prediction of flow rates. The higher the leakage rate is identified by the high RMS peak value which depends on the media of the leak environment. This happens due to increased water velocity and turbulence at the leak point [10]. Measurement vibration using Laser Dopler Vibrometer (LDV) shows emphasize the previous theory that are the frequency of the first harmonic increases with the pump rotation and the amplitude of the first harmonic increases with increasing water flow rate [11].

2.2. Determine Pipe Leak Location

Pipeline leak detection study by observing the behavior of pressure and flow rates along the pipe using computational fluid dynamics (CFD) modeling using the ANSYS FLUENT application in steady state and turbulent conditions has been conducted [12]. By increasing the diameter of the leak hole, the volume of liquid leaving the hole becomes larger and affects the hydrodynamics around the leak in the pipe. Monitoring the pressure gradient and flow rate along the pipe is very important tool to identify leaks because the area is affected by interference from the upstream and downstream side leaks.

Micro Electro Mechanical Systems (MEMS) sensors is used to measure flow induced vibrations where leakage points are outside the reach of the sensor [13]. Investigations were carried out to get the relationship between flow induced vibration and pipe pressure. This study shows that significant changes in pressure are always accompanied by significant changes in surface acceleration so that pressure monitoring can be changed to acceleration as well as monitoring of pipe vibrations.
3. Methodology
To achieve the objective of this study, laboratory scale experimental approach is taken. An experimental setup is designed to replicate the existing conditions of the supported leaking pipes in water distribution systems.

The fluid used is fresh water with a density of 1,000 kg/m³ and in room temperature (30 °C) flowed through 1 inch diameter PVC pipe along 369 cm using pump flow rates: 17.2 liter/minutes. An accelerometers are installed in the pipe wall at a distance of 7 cm from the source of fluid flow. The accelerometer will be connected to the computer through a Testing Measuring Recording (TMR) device. The signal generated by the accelerometer will be analyzed through the Dewesoft X3 software application. Three valves will be installed at the point 145 cm, 170 cm and 195 cm from the inlet by opening the three valve by 15° and 45° simultaneously to have small leaks and big leaks respectively. The configuration of the acceleromater, pipa and leak points are illustrated in Figure 1.

![Figure 1. Experiment schematic diagram](image)

Accelerometer is used to measure the magnitude of the frequency and the amount of acceleration over the time before and after the pipe leaks. TMR devices are used to convert the acceleration signal generated by the accelerometer into a digital signal. Data recording is carried out for 5 seconds in the condition of the pipe not leaking and pipe leaked with a constant flow rate.

4. Results
Analysis effect of the vibration spectrum on FFT diagram in condition pipe does not leak and leak are illustrated in Figure 2. The change in the dominant amplitude component from no pipe leak to pipe leak is the shift in the dominant frequency from 25,02 Hz to 34,79 Hz and from 61,04 Hz to 65,31 Hz followed by an increase in the amplitude value from 0,0096 m/s² to 0,0122 m/s² and 0,00682 m/s² to 0,0222 m/s².

![Figure 2. Vibration spectrum in the condition of not leak (blue) and big leak (green)](image)
However, according to Figure 3, no pipe leak and small pipe leak are difficult to distinguish on FFT diagram. On the other hand, small leak and big leak are easy to be identified through Figure 3. The change in the dominant amplitude component from small leak to big leak is the shift in the dominant frequency from 26.25 Hz to 34.79 Hz and from 57.34 Hz to 65.31 Hz followed by an increase in the amplitude value from 0.00507 m/s² to 0.0114 m/s² and 0.00651 m/s² to 0.0194 m/s². The result shows that spectrum vibration of small pipe leak similiar with no pipe leak.

![Figure 3. Vibration spectrum in the condition of not leaks (blue), small leaks (green) and big leaks (red) ](image)

The difference in the vibrational spectrum of pipes with large leaks at 145 cm, 170 cm and 195 cm is shown in Figure 4. The dominant frequency shift occurs from the three variations of the leakage point. The leakage distance further away from the sensor point causes the dominant frequency to shift from high frequency values to smaller frequency values. The peak of the spectrum at leakage at 145 cm occurs at a frequency of 93.98 Hz, at 170 cm occurs at a frequency of 84.84 Hz and at 195 cm occurs at a frequency of 73.85 Hz.

![Figure 4. Vibration spectrum of pipe leaks at 145 cm (blue), 170 cm (green) and 195 cm (red) ](image)

5. Conclusion
The conclusion of pipeline leak detection with variations in leak types and leak distances using the FFT diagram is as follows:

1. Spectrum vibration on pipe not leak is almost no different with small pipe leak spectrum vibration.
2. Changes in the vibrational spectrum from the condition of small leakage pipe to big leakage pipe are changes in the dominant frequency from those scattered in several frequencies with the same acceleration value to a narrower frequency range with higher acceleration values.
3. Changes in the vibrational spectrum caused by the further away leakage points towards the vibration sensor are decreasing dominant frequency.
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