Comparative Study of Vibration Signal Processing on Pipe Leak Case

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Abstract. This article proposes a model for a real-time monitoring system capable of identifying the occurrence of single event leak in pressurized water pipelines. The model utilizes two accelerometers which are installed on upstream and downstream of the leak. Experiments are conducted on an inch PVC pipeline and the vibration signal results are displayed and recorded into laptop with installed software. The vibration signal derived from each accelerometer are assessed and analysed by Fast Fourier Transformation (FFT) and Cross-Power Spectral Density (CPSD). The results indicate that by using this method, leak can be identified while the sensor’s positioning can be vital in leak detection.

1. Introduction
Leaks in water pipelines have become a very significant problem throughout the world, especially in densely populated locations, whose activities intersect with pipeline installation networks. Detecting leaks in the water supply network is a very interesting problem because the availability of clean water is a vital requirement in everyday life and clean water that has economic value [1]. Most of the current water supply network is made of Polyvinyl Chloride (PVC) plastic pipes, CPVC (Chlorinated Polyvinyl Chloride), HDPE (High Density Polyethylene), PP-R (random polypropylene) and PEX (Cross-linked Polyethylene), because of its lightweight, strong enough for drainage pressure, the price is cheaper than carbon steel pipes and resistant to corrosion.

Accelerometers have drawn the attention of researchers recently where they can be utilized as a full leak detection system to detect vibration signals that are emitted by leaks [2]. The most popular approach to water leak detection is to use acoustic/vibration sensors or pressure transducers attached to the surface of a pipe [3,4,5]. When two sensors are used, the leakage location can be determined by estimating the time difference through correlation of the receive signals [6].

Accelerometers are inertial measurement devices that convert mechanical motion into a voltage signal as illustrated in Figure 1. The signal is proportional to the vibration’s acceleration using the piezoelectric principle. When the accelerometer is subjected to vibration, the mass exerts a varying force on the piezoelectric crystal, which is directly proportional to the vibratory acceleration. The charge produced by the piezoelectric crystal is proportional to the varying vibratory force [7].
2. Methodology

The collection of studies that study the method of detecting leaks in pipes, especially using accelerometers. Literature studies are also carried out for various methods in processing the generated vibration signals, including their accuracy in determining leakage [8,9]. In addition to conducting experiments on a laboratory scale, analysis is also carried out using Dewesoft X3 and LabVIEW 2018 software.

This research is conducted by making a model made of PVC pipes and water originating from a reservoir. The fluid used is water, which is pumped through PVC pipe that are installed horizontally relative to the surface of the ground and supported by pipe support at three points along the pipe. There are three pumps (pump P1, P2 and P3) with different pumping capacity which representing different water debit. While the leak itself positioned in the middle of the pipelines, the leak is simulated by opening the 1-inch valve which is symmetrically positioned refer to each of accelerometer. The sensors (accelerometers) are accelerometer A1 which located upstream the leak, and accelerometer A3 is located downstream the leak location which is shown in Figure 2.

The vibration signal measurement results then translated into Fast Fourier Transform (FFT) and Cross-Power Spectral Density (CPSD) which are processed using the National Instrument LabVIEW 2018 software application on a laptop. Experiment conducted analyze the ability to detect leaks and compared the methods parameters so that research conclusions could be drawn.

Figure 2. Experimental setup as model of pipeline leak and sensor positioning
3. Results

All the monitored burst leaks are associated with polyvinyl chloride (PVC) service pipes of small diameter (1 inch). The leak is simulated by 50% opening the valve, and all the same for each pump (P1, P2 and P3). Each sampling’s duration is 21 and 23 seconds, while it represents the steady condition for each scenario.

3.1. Fast Fourier Transform

Fourier Transform (FT) is widely used in signal processing in terms of Fast Fourier Transform (FFT) as it is a powerful tool that allows one to analyze a particular signal in the frequency domain. Discrete Fourier Transform is used in many disciplines to obtain the spectrum or frequency content of a signal, and to facilitate the computation of discrete convolution and correlation [10].

The signal’s frequencies produced by FFT as described in Figure 3, 4 and 5, show the waveforms which blue line represents waveforms of No-leak signal, and red line represents Leak signal. It is worth noticing that the vibration signals analysed in this paper are characterized by relatively high frequencies, whereas values reported in the literature for burst leaks occurring in plastic pipes are typically below 100Hz [11,12].

Corresponding to Figure 3, the difference between No-leak and Leak condition for Accelerometer A1 can be distinguished distinctly. The red graph in the region between 60 – 100 Hz represent the peak amplitude 0.028 m/s² in frequency 65 Hz, compared with blue graph which is No-leak condition with frequency amplitude 0.005 m/s² in the same frequency. But this is not occurred on Accelerometer A3, which is positioned on the downstream of the leak location. The frequency amplitude of No-leak condition (blue line) is higher than the Leak graph (red line).

![Figure 3. FFT for Pump P1 measured by Accelerometer A1 and A3 for No-leak and Leak condition](image-url)
The same condition also occurred on Pump P2 as being illustrated in Figure 4. The P2 pump’s flow has higher flow rate (1.800 l/hr), compared with Pump P1 (850 l/hr). The Accelerometer A1 shows Leak region occurs at 95 Hz, while the frequency amplitude is 0.0048 m/s². The Accelerometer A3 indicates the frequency amplitude for Non-leak is 0.15 m/s² which is slightly higher than Leak condition (0.14 m/s²) in the same frequency 47 Hz.

![FFT for Pump P2 measured by Accelerometer A1 and A3 for No-leak and Leak condition](image)

**Figure 4.** FFT for Pump P2 measured by Accelerometer A1 and A3 for No-leak and Leak condition

In Figure 5, it is illustrated that Pump P3 which has the highest flow rate (2500 l/hr), Accelerometer A1 shows Leak region occurs at 89 Hz, and the frequency amplitude is 0.043 m/s². The Accelerometer A3 indicates that the frequency amplitude for Non-leak is 0.17 m/s² higher than Leak condition 0.02 m/s² in frequency 105 Hz.
Figure 5. FFT for Pump P3 measured by Accelerometer A1 and A3 for No-leak and Leak condition

3.2. Cross-Power Spectral Density
Cross spectral analysis allows one to determine the relationship between two time series as a function of frequency. PSD is the distribution of power along the frequency axis. Cross spectral density is the same, but using cross-correlation, so one can find the power shared by a given frequency for the two signals [13,14]. Using National Instrument LabVIEW 2018 signal processing toolbox, to generate Power Spectral Density for signal from Accelerometer A1 and A3 for each scenario, the parameters configuration used is illustrated in Figure 6.

Figure 6. CPSD parameters configuration in NI LabVIEW 2018
The CPSD graph results are shown on Figure 7. The results indicate that the peak of power distribution for Leak condition which is shown by red line, is 0.00085 in the frequency 60 Hz. No-leak graph in white line, has smaller peak compare with Leak condition, which is 0.0005 in the frequency of 30 Hz.

![Figure 7. CPSD for Pump P1 measured by Accelerometer A1 and A3 for No-leak and Leak condition](image)

The CPSD graph results are shown on Figure 8, illustrate the result for Accelerometer A1 the peak of power distribution for Leak condition which is shown by red line is 0.0135 at the frequency of 75 Hz. While Accelerometer A3 shows the peak of power distribution for Leak condition is 0.0425 at frequency 60 Hz.
Figure 8. CPSD for Pump P2 measured by Accelerometer A1 and A3 for No-leak and Leak condition

Figure 9 The CPSD graph results shows that the peak of power distribution for Leak condition which is shown by red line for Accelerometer A1 is 0.00133 at 80 Hz, while for Accelerometer A3 the peak of power distribution for No-leak condition is 0.0172 at 160 Hz. It is anomaly since previous experiments show opposite results.

Figure 9. CPSD for Pump P3 measured by Accelerometer A1 and A3 for No-leak and Leak condition
4. Conclusion
This paper presented the study to develop a signal processing method which may help to identify leak on plastic water distribution pipes by using FFT and CPSD. In some cases, where the leak cannot be directly detected by the difference in acceleration amplitude, and the vibrations caused by the flowing water overwrite the vibrations from the leak, the leak can still be detected by vibration analysis in the frequency domain.

FFT is also essential for providing the frequency area that the Leak No Flow signal is present. The system provided very good results by comparing the FFTs of observed signals. CPSD was used, similarly to wavelet analysis, in order to confirm the FFT results using other methods [3,15].

This paper shows that given a sample of burst leak vibrations on a model PVC pipe, the system can be designed to compare signal’s frequency behaviour in real conditions and decide whether there is a leak or not. Recognition rate is lower for plastic pipes, because of its characteristics concerning acoustic wave propagation: signal attenuation, low speed of sound, noise, and etc [16]. It is recommended to use cross-correlation of vibration or acoustic signals as a tool for leak location in water distribution pipes, since the most widely used correlators utilise the so-called Basic Cross-Correlation (BCC) function. The BCC function may be computed by taking the inverse Fourier transform of the Cross Spectral Density (CSD) function of a leak signal, measured either side of the leak [17].

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