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Investigation of Internal Gas Leakage on the Gate Valve using Acoustic Signal

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Abstract: The gate valve is primarily used for starting/stopping the flow of fluids. It is suitable for most fluids such as water and chemicals as well as air, steam and gas in petrochemical and refinery plants that require high temperature and low pressure. The aim of this study is to define the frequency domain using AE signals, such as RMS and ASL, to determine the internal gas leakage. The conducted experiment employed a 4-inch diameter gate valve installed in the middle of the pipe length. To simulate industrial applications, the AE signals were observed at low-frequency (between 18.6 kHz to 19.5 kHz), with inlet pressures between 100 to 800 kPa and leakage rates between 0.5 percent to 2 percent. The frequency domain between 18.6 to 19.5 kHz and the inlet pressure of 100 to 800 kPa were displayed as the Root Mean Square (RMS) and Average Signal Limit (ASL). The pressure difference between the inlet and outlet influences the AE signal. The frequency spectrum can be correlated with the pressure leakage, thus providing leakage conditions. Therefore, the obtained results can be employed in industrial applications.

Keywords: Acoustic emission, gate valve, leakage, frequency domain

1. Introduction

Generally, gate valve leakage can be separated into two types: external leakage and internal leakage. The external leakage is easily traced since the medium outflow can be visually seen. However, internal leakage of the gate valve requires pipeline re-installation which can cause accidents or hazards. The situation can become dangerous and involve many causalities due to fires, explosions, poisoning or accidental burns [1]. This problem influences product quality and causes energy wastage, equipment corrosion, material consumption and environmental pollution [2]. The gate valve, also known as a sluice valve, is located in a small space within the pipe axis. It restricts the fluid flow when the gate is fully opened. The gate faces are usually wedge-shaped in order to apply pressure on surfaces, however, some are parallel. Gate valves operate in a linear motion; the valve slides either up or down to control the fluid flow. They are suitable for operating in either closed or open conditions [3]. However, gate valves are unsuitable for regulating the flow or pressure

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of fluids or for operating in partially open conditions because the fluid flow rate is indirectly proportional to the size of the valve opening [4].

In the fluid delivery pipeline system, the gate valve plays an important role as a control component. The important functions include diversion, cut-off, throttling, check, shunting as well as pressure relief, managing to change the passage section and the flow direction of the medium. Therefore, gate valves are widely used in several industries such as the petroleum/oil industry, chemical industry, etc. [5]. Due to rapidly increasing industrial developments, the demand for gate valves in various industries has been constantly high. However, the problem of detecting internal leakage still remains. Currently, the conventional method requires frequent opening and closing. For this reason, we propose the use of acoustic emission (AE) as a new technique for detecting and monitoring the internal leakage of valves. The technique offers continuous monitoring throughout the entire operation process, allowing the detection of gradual changes in the valve [4]. By using this technique, valve maintenance can be accomplished with accurate predictions and analyses. Moreover, it will be easy to disassemble and assemble the valve from the pipe to inspect its condition.

Localisation in acoustic emission is the existing signals that generate a transient elastic wave when a material is subjected to an external force, such as pressure. Its local source then tends to produce energy in the form of stress-waves which propagate along the wall of the material. Valve leakage can be detected since the AE leakage signal has a continuous waveform that can be analysed using several techniques. AE is also highly sensitive and can be used for detecting weak signals without inhibiting process development [6]. The signals produced by internal leakage in the valve pipeline system are part of the typical acoustic emission phenomenon [7], [8]. Changeable AE signals may appear when gas passes through the internal leakage point. Theoretically, this can cause inefficiency and may alter the mathematical model of the valve body between the internal leakage and AE signals. A method to determine the internal leakage of gate valves remains unexplored. Inconsistent measurements can be influenced by the different flow motions of gas.

Therefore, the objective of this study is to obtain the frequency domain and percentage of leakage using AE signals. Different inlet and outlet pressures were applied to obtain the relationship between internal leakages. In order to measure the effect, a test loop system was developed using a 4-inch diameter gate valve installed in the middle of a pipeline.

2. Acoustic Signal from Valve Leakage

The acoustic signal comes from the high-frequency stress wave induced by turbulence flow. This turbulence flow is due to the random flow of fluid going through a valve's leak hole. The frequency of the signal usually varies, from 5kHZ to 1MHz, and can be easily identified by environmental noise from the factory. Researchers had discovered that the measurement of the flow rate and automatic online control can be achieved by monitoring the sound level of valve noise [9]. The results demonstrated that the frequency components related to leakage can be seen from the AE signal with background noise. Xu et al. (2016) further studied the AE characteristics of leakage in two valves (the steam ball valve and water ball valve) under a situation of different leakage modes. It was concluded that the valve's leakage rate is directly proportional to the sound amplitude. It was found that the theoretical relationship between AE signals and the internal leakage rate of the valve (the ball valve) can estimate the rate of gas leakage in the valve. Zhu et al (2015) later applied an online detection method using AE to characterise signal parameters for the internal leakage of gate valves. It was revealed that the different pressures affected by internal leakage are the greatest internal structure at both ends of the gate valve. Thus, it has been proven that the AE technique can be applied for detecting inner leakage in the gate valve. This work examines gate valve leakage using acoustic emission detection for condition-monitoring. Frequency spectrum analysis was used to describe the frequency-domain characteristics of the AE signal. The Fourier Transform (FT) spectrum analysis and spectrum estimations are the typical spectrum analysis methods applied in this study.

2.1 Fast Fourier Transform (FFT)

Fast Fourier Transform (FFT) is a tool used for mathematically reduce any signal that varies concerning time to a series of sinusoidal terms and for analysing the waveform data. It is also useful for the natural frequency of vibrated system detection to reduce the vibrations [11]. Besides, a Fourier series can decompose any periodic signal or function into the sum of simple goniometric and being able to transform the time domain into a digital signal into the frequency-domain signal. This helps in determining modal parameters of the vibrating system, such as an unusual signal that occurred in the normal signal.

For the Fourier series and transformation, can write this function by the infinite series for a period $-T \leq t \geq T$ as below based on cited by [12];

$$x(t) = \frac{a_0}{2} + \sum_{k=1}^{\infty} \left[a_k \cos \frac{\pi k t}{T} + b_k \sin \frac{\pi k t}{T} \right] \tag{1}$$

where x(t) is the function of the signal in the time domain, and a_k and b_k are the coefficient of the series to be determined. The integer k corresponds to the frequency of the wave.

For the AE signal analysis, the Fourier Transform (FT) spectrum analysis and spectrum estimation are a typical method used for analysing the signal as cited in [13]. Nonetheless, FT is only being able to retrieve the frequency content of the signal while losing its temporal information. To analyse the AE wave signal that occurs in the gas flow inside the valve, the FFT feature used to analyse the AE signal indicates that the frequency does not depend on the size and pressure but is highly dependent on the type of failure that occurs. For instance, the peak frequency for valve failure is low compared to damage to the valve mechanism itself. Therefore, the type and cause of valve failure are important parameters that need to be considered in analysing the FFT peak frequency.

2.2 Continuous Wavelet Transform

Theoretically, the wavelet transform (WT) is a signal processing method that overcomes the limitation of Fourier analysis by simultaneously performing time-frequency analysis and using the correlation translation and expansion of a function, called mother wavelet, to describe the signal. The continuous wavelet transform reveals the local transient features in time-frequency domains due to the dilation and translation of the wavelet. This helps in effectively extracting the time-frequency signal features. CWT also eases the analysation process of time-varying non-stationary acoustic signals [14]. In addition, the increment of the leak severity will increase the amplitude of the waveform, indicating that the acoustic signal contains more energy compared to the de-noised signal. The energy distribution can be further analysed in CWT since its distribution of energy will be different. The energy of the normal state spreads more evenly compared to the energy of the leak state, which only concentrates on the low-frequency component. Therefore, the leak information's characteristics can be effectively extracted by using wavelet transform.

2.3 AE Parameters

Acoustic emission employs an elastic wave generated by rapidly changing the stress state of an acoustic event. The acoustic emission energy is a material dependent and related to the leakage. The changes of the stress wave are due to the application of the valve leak in the pipeline which is rapid enough to transmit energy to the surrounding material. As mentioned, the AE energy is a material dependent and related to the leakage. The leakage energy, if taken as a material property, should be constant and independent of the method of measurement. The continuous transmission of energy is determined by the valve leakage condition. The energy distribution from the pressure pulse in the gas leakage travels, spreads and scatters through a material to the point of detection. The signal energy is defined as the internal voltage squared vs the time curve over the signal length [15], [16]. The signal energy (digitized) is defined as:

$$E = \int_0^t v^2(t)dt \qquad (2)$$

Where E is AE energy in V^2s ; $v(t)$ is the amplitude of the waveform in volts (V); t is time in seconds.

The amplitude is the highest peak voltage attained by the waveform and it is an important parameter to determine the detectability of the AE event. Since the continuous waves produced are from fluid flow and there is continuous friction between the surface, the continuous amplitude is fluctuating. The amplitude of the wave decreases as the distance increases. Furthermore, The average signal level (ASL) measures the continuously varying and averaged amplitude of the AE signal [10]. For the continuous air leakage flow in valve monitoring, the root mean square is applied to observe the activity of the condition monitoring. The AErms is the AE signal in the time domain or frequency domain and can be defined as:

$$AE_{RMS} = \sqrt{\frac{1}{T}\int_{t_0}^{t_{0+T}} v^2(t)dt} \qquad (3)$$

where $v(t)$ is the amplitude of the waveform in volts (V), t_0 is the initial time, T is the integration time of the signal in seconds.

3. Methodology

This section describes the conducted experiments. The condition of the valve was simulated to show when a leak takes place. To accurately simulate what occurs in the industry, some parameters were taken using acoustic transmitting tools which will be used as reference data in the future. Under normal circumstances, the valve closes tightly to block any gas from passing through but when there is a valve failure due to prolonged use, some gaps will be present between the valve and the seal. This will cause an internal leak in the valve, which is not visible. Leakages that occur at a small rate will be difficult to detect if using methods other than acoustic transmission.

The flow system for testing this experiment was accomplished using a 4-inch diameter pipe with a length of 10 feet. The gate valve was installed in the middle of the pipe to stabilise the airflow at the inlet and outlet areas. For air pressure detection, four pressure gauges were installed along the pipe to monitor the flow of air pressure throughout the pipe. The air was supplied to the pipe by directly connecting air pipes from the storage tank located in the Multiphase Flow Rig. The capacity of the air storage tank available at this facility is 1000 litres, and the maximum reach is up to 900 kPa. The air supply was continuously and consistently done by the storage tank to obtain accurate flow data (Fig. 1).

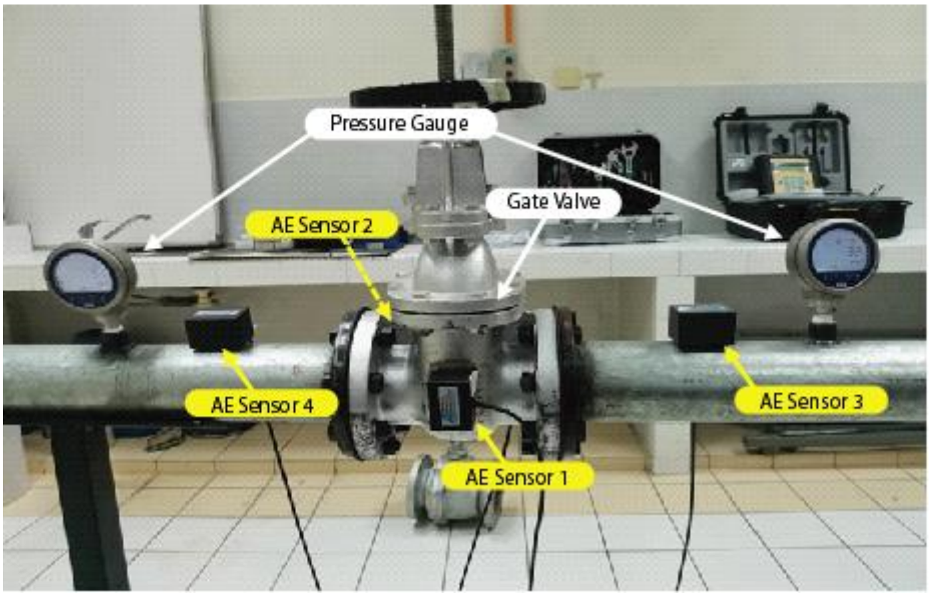

Fig. 1 - Experimental arrangement for gate valve

A 4-inch gate valve was installed in the middle of the pipe, as shown in Fig. 2. This is the actual position in the industry which takes into account the back flow that will occur in the pipe. Regarding the valve size selection, most industries use the 4-inch valves. Air flows into the piping system and can be then controlled by fully opening the inlet valve. When the pressure reaches the entire pipe, the inlet valve will close, and the gate valve will open according to the leakage condition. The outlet valve will then be fully opened. To simulate failure, the gate valve was left open at 0.5 to 2 percent gap. The percentage of leakage simulate by opening the valve based on rotation of the handwheel. the gate valve slowly opened until it reached 0.5% of leakage which is equivalent to 25 % of the rotation of the handwheel as shown in table 1. If there is a situation where the gate valve cannot completely close, pressure will occur on the gate valve. When a small opening is made and there is a leakage in the valve, turbulent gas flow will be present.

Table 1 - Detail of valve displacement and rotation angle of handwheel at different gap valve

Gap valve (%)	Valve displacement (Rotation angle of handwheel)	Displacement (mm)
0.5	90^{0}	0.51
1	180^{0}	1.02
1.5	270^{0}	1.53
2	360^{0}	2.04

An acoustic emission sensor was mounted on the valve body to measure the noise signal caused by air leakage. To identify the appropriate type of sensors and to obtain the required frequency range due to the leakage signal, a total of three sensor types were used: low frequency, intermediate frequency and wideband frequency. Sensor R1.5 is defined as a low energy with high sensitivity AE sensor and incorporating a low-noise input. Since it can be measured continuously in pipeline leaks and in smaller leakages [17]. The results of the test revealed that the R1.5 sensor is suitable based on its ability to detect weak signals, and its detection is appropriate to the type of gate valve used. The sensor was connected to the PCI-2 Based AE system for continuous data transfer and signal monitoring. Various parameters were obtained as a result of this experiment, however, the primary focus was on the occurring frequency range for each leak simulation [18]. The AEwin software was utilised for data collection as well as for the continuous monitoring of leakage conditions which occurred at the gate valve until the pressure drop was 50 kPa. The acquired data was processed and analysed using NOESIS Ver. 9 software. The software was used to assess the collected signals for each leak simulation so as to continuously measure the AE signal; this included the domain frequency data, Average Signal Level (ASL) and Root Mean Square (RMS). It was difficult to obtain a consistent flow of air pressure on the pipe. However, with the use of air storage tanks, smooth airflow was accomplished and further measurements were made by the AE system.

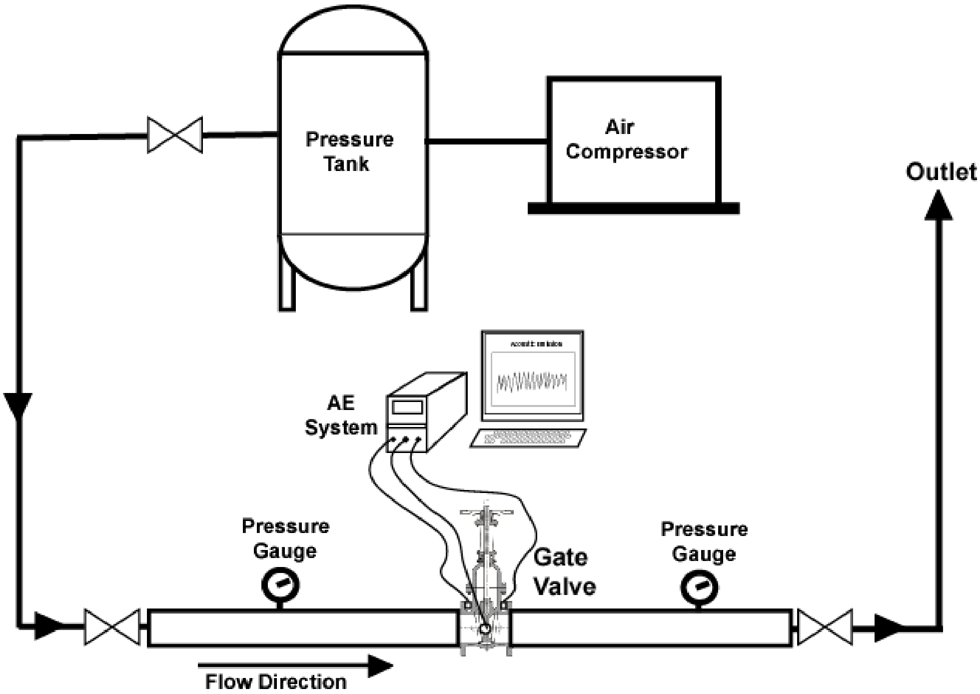

Fig. 2 - Schematic diagram of the investigation set-up

4.0 Results and Discussion

4.1 Effect of Frequency Domain on AE and Leakage Percentage

Fig. 3 presents a series graph for the frequency spectrum of the gate valve at different inlet pressures. The inlet pressures varied (100 kPa to 800 kPa) to simulate leakage conditions (Zhu, 2015). The graph displays different movements of gas flow in the piping system through the valve at 0.5 to 2 percent leakages. The significant frequency domains were found to range between 10.5 to 40 kHz and the highest operating frequency was obtained at the range 18.6 kHz to 19.5 kHz. Moreover, the maximum magnitude increased as the inlet pressure increased. On the other hand, a low frequency was found at a lower leakage due to longer pressure release time. A slightly higher magnitude was noted at 1 percent leakage and this continued to increase at 1.5 percent due to the higher noise of air flow. For a 0.5 percent leakage, the magnitude for the frequency always remained low since the leakage flow was low and the conducted measurements required significant time in this experiment. For the 1 percent leakage, the frequency range exhibited a slightly higher rate compared to the 0.5 percent. When turbulent flow and backflow occurred at 1.5 percent, the amplitude drastically increased yet remained within the stated frequency range. From the graph measurements, it can be concluded that the frequency will increase if the the flow velocity increases.

4.2 Continuous Wavelet on Gate Valves

The continuous wavelet of the gate valve was used for the filtered signal frequency. Fig. 4 presents the waveform and wavelet transform obtained from this experiment. Since the signal is free from noise, obtaining its frequencies did not pose any difficulty, and the information needed was derived without any uncertainty. From the Fig. 4(a), it's a waveform obtained from the experiment. The data from waveform will be used to simulate the pattern using NOESIS. Fig. 4 (b) is a wavelet transform image by simulating using NOESIS software. The red colour is a indication of operating frequency detected for a flow of leakage mode. It's shown the signal pattern when the leakage occurs. The frequency spectrum was observed to range between 18.6 to 19.5 kHz, which can be assumed to be the optimised frequency of the gate valve. Although the study of wavelets is uncommon, it can solve the challenge of determining a specific frequency range.

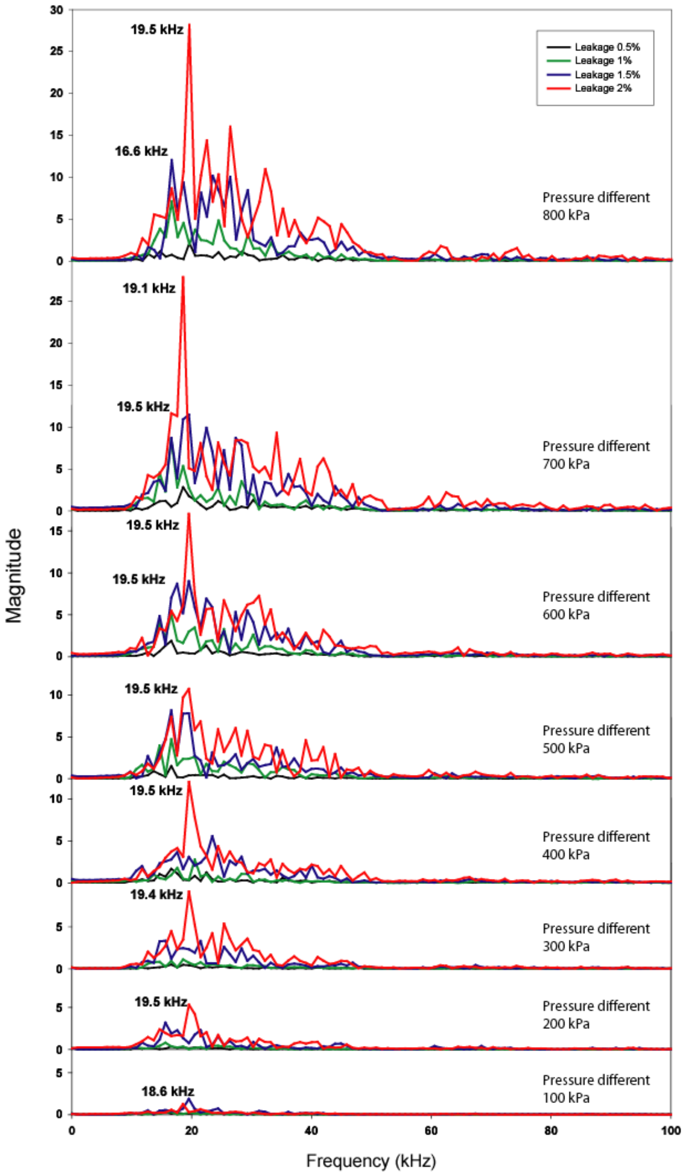

Fig. 3 - Series of frequency spectrum for gate valve

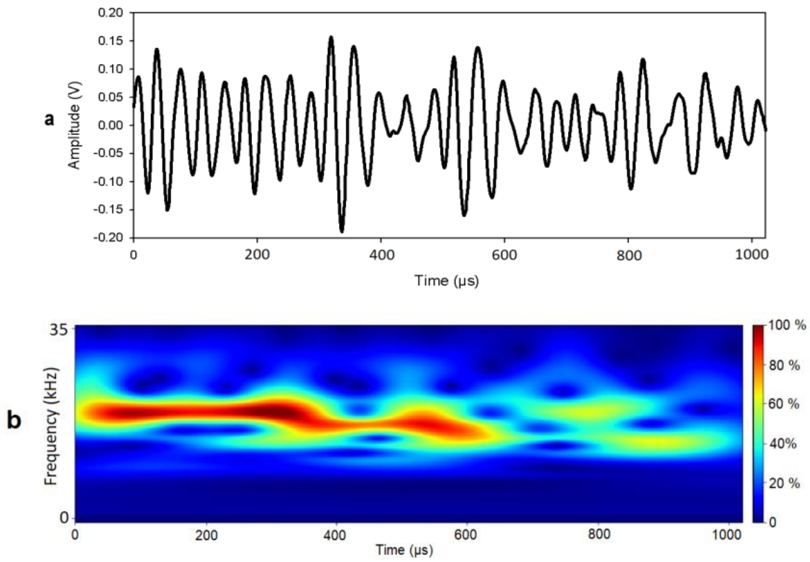

Fig. 4 - Signal generated form the leakage: (a) waveform; (b) Continuous Wavelet Transform

4.3 Relationship between AE Parameters and Pressure Differences for Internal Leakage

To determine the correlation between the inlet and outlet when a pressure drop occurs, several AE parameters must be interpreted to estimate the level of leakage. For the results of this experiment, all AE parameters were used to monitor the flow conditions at the gap where the leaks occur. The energy source of the leakage was measured to detect the leakage level associated with the released energy, as shown in Fig 5. This rapid energy release is detected from the leakage. The leakage can be characterised by four types of leakage modes. This result presents significant data when comparing every leakage mode. The biggest leakage indicates higher energy release. Fig. 6 displays the continuous amplitude signal related to the turbulence pressure from the valve. The high amplitude of 68 dB was related to the highest leakage percentage, which was two percent. From the graph, it can be seen that higher amplitude is attributed to higher continuous flow release from the valve. This is due to the pressure wave in the pipe or residual pressure in the valve itself. The results revealed significant changes for every leakage mode associated with the pressure difference. Fig. 7 shows a comparison of the data obtained for ASL as a result of the percentage leakage that occurred on the valve. Four flow conditions were performed: 0.5, 1, 1.5 and 2 percent of leakages. For this data, the timing of events played a crucial role for obtaining an estimation of leaks as a result of pressure differences. At the level of 800 kPa, the obtained amplitude was 70 dB, while for ASL, it was 60 dB maximum. These results show similarities with the ascending pattern acquired by Zhu et al. (2014). These outcomes indicate that the higher the pressure difference, the higher the ASL data.

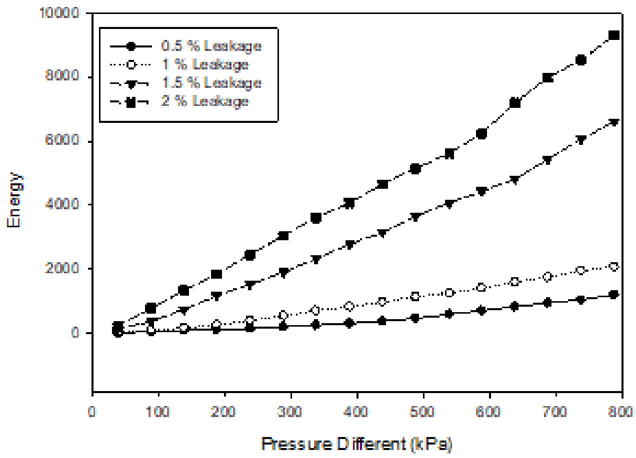

Fig. 5 - Different pressures vs energy

The results from the ASL information are insufficient and therefore, depending on its signals alone would be inadequate. The RMS signal should also be assessed, as presented in Fig. 8, to provide further information on the leakage. Fig. 8 displays the graph data obtained from the pressure difference and results of RMS. A significant increase for all leakage modes was present. At 800 kPa pressure, the RMS was at 0.07 for 2 percent leakage; while for 1 percent leakage, the RMS was at 0.01. The significant increase at 2 percent is due to the very fast pressure drop as well as the drastic increase of turbulent flow. Using the information from the RMS signals, a relatively good relationship can be seen, with values at an upward state due to the effects of the pressure differences. The RMS value monitoring is related to time as well as the pressure drop during the experiment. The use of low frequency transducers has shown a favourable plot increase as a result of the leak. The increase is almost linear with the leak. The outcomes show it is comparative between the leakage mode and the pressure difference.

5. Conclusion

The AE gate valve signal acquisition platform was investigated, analysed and established for internal leakage characteristics of the gate valve with frequency, wavelet, AE RMS and ASL signals. Internal gas leakage tests for gate valves in different operational conditions revealed the signal characteristics. The internal leakage rate for the gate valve measures the internal leakage characteristics of the valve and evaluates its failure. A signal acquisition platform was established based on the gate valve's internal leakage system. The internal leakage characteristics of the gate valve were effectively scanned; possible internal leaks at various frequency ranges were tested; and ASL, amplitude and RMS were successfully plotted.

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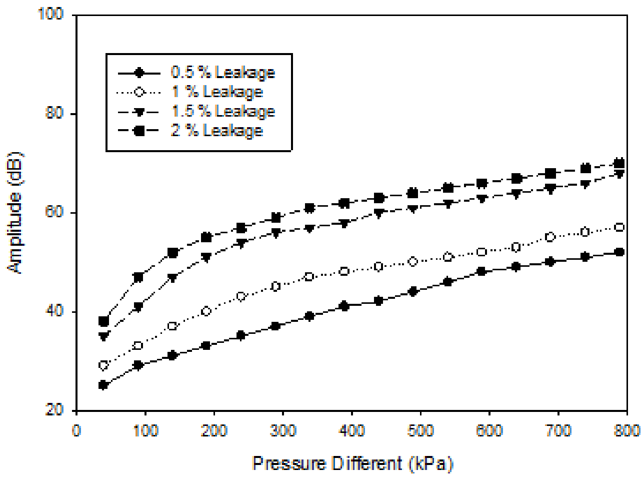

Fig. 6 - Curve of different pressures vs amplitude

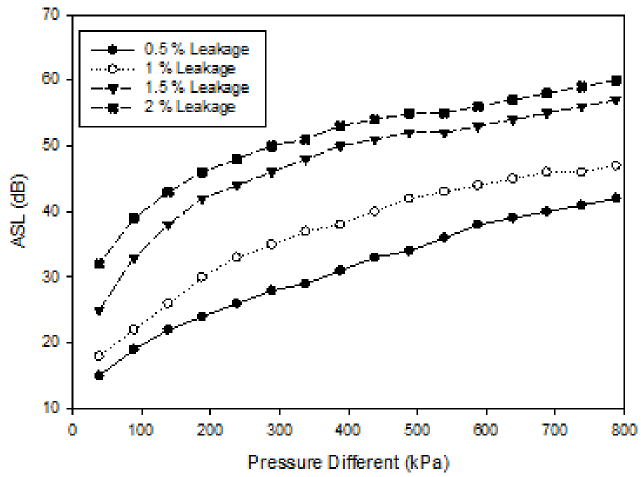

Fig. 7 - Curve of different pressures vs ASL

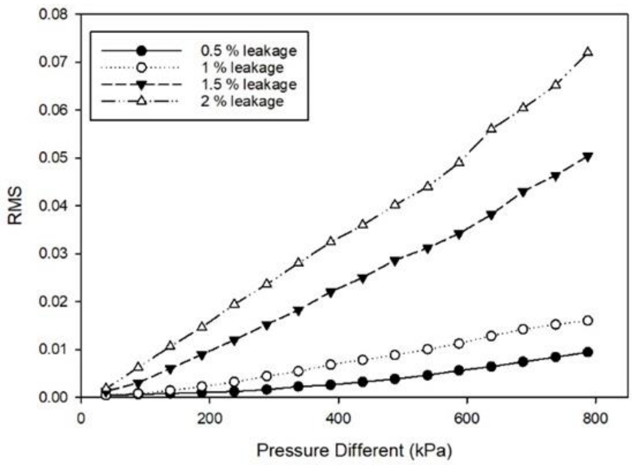

Fig. 8 - AE RMS data obtained from different pressures for all leakage modes

References

[1] C, Zhang., J, Zhang., X, Yu., & S, T, Tu. (2018). Study on on-line monitoring of valves leakage. Proceedings of the 7th Asia-Pacific Workshop on Structural Health Monitoring, APWSHM 2018, pp. 547–558.

[2] L, Zhu., B, Zou., S, Gao., M, Jiang., & Z, Li. (2015). Research on gate valve gas internal leakage AE characteristics under variety operating conditions. Measurement: Journal of the Inetrnational Measurement Confederation, vol. 44, no. 6, pp. 1059–1072.

[3] C, K, Kim., S, M, Lee., & C. M. Jang. (2019). Performance analysis of a ball valve used for gas pipelines by introducing nondimensional parameters. Advances in Mechanical Engineering, vol. 11, no. 1, pp. 1–10.

[4] A, Rondeau., E, Lafargue., & F, Cartier. (2018). Leakage noises in valves. Proceeding of Meetings on Acoustic, vol. 030015, no. 2017, p. 030015.
[5] S, Pan., Z, Xu., D, Li., & D, Lu. (2018). Research on detection and location of fluid-filled pipeline leakage based on acoustic emission technology. Sensors (Switzerland), vol. 18, no. 11.
[6] S, M, Ali., K, H, Hui., L, M, Hee., & M. S. Leong. (2017). Automated valve fault detection based on acoustic emission parameters and support vector machine. Alexandria Engineering Journal.
[7] J, Yan., Y, H, Hu., Y, Hong., Z, Feng., L, Zhen., W, Ping., et al. (2015). Nondestructive Detection of Valves Using Acoustic Emission Technique. Advances in Materials Science and Engineering, vol. 2015.
[8] L, Yu., & S, Z, Li. (2017). Acoustic emission (AE) based small leak detection of galvanized steel pipe due to loosening of screw thread connection. Applied Acoustics, vol. 120, pp. 85–89.
[9] C, Guo., M, Gao., & S, He. (2020). A review of the flow-induced noise study for centrifugal pumps. Applied Sciences, vol. 10, no. 3.
[10] C, Xu., G, Han., P, Gong., L, Zhang., & G, Chen. (2016). Quantification of Internal Air Leakage in Ball Valve using Acoustic Emission Signals. 19th World Conference on Non-destructive Testing (WCNDT), Germany, pp. 1–9.
[11] S, Davoodi., & A, Mostafapour. (2013). Modeling acoustic emission signals caused by leakage in pressurized gas pipe. Journal of Nondestructive Evaluation, vol. 32, no. 1, pp. 67–80.
[12] T, Harčarik., J, Bocko., & K, Masláková. (2012). Frequency analysis of acoustic signal using the Fast Fourier Transformation in MATLAB. Procedia Engineering, vol. 48, pp. 199–204.
[13] Z, Li., H, Zhang., D, Tan., X, Chen., & H, Lei. (2017). A novel acoustic emission detection module for leakage recognition in a gas pipeline valve. Process Safety and Environmental Protection. vol. 105, no. 51, pp. 32–40.
[14] R, Xiao., Q, Hu., & J, Li. (2019). Leak detection of gas pipelines using acoustic signals based on wavelet transform and Support Vector Machine. Measurement: Journal of the Inetrnational Measurement Confederation, vol. 146, pp. 479–489.
[15] A, Beattie. (2013). Acoustic emission non-destructive testing of structures using source location techniques. Albuquerque and Livermore, no. September, p. 128.
[16] Y, J, Song., & S, Z, Li. (2018). Leak detection for galvanized steel pipes due to loosening of screw thread connections based on acoustic emission and neural networks. JVC/Journal Vibration and Control, vol. 24, no. 18, pp. 4122–4129.
[17] K, Ono. (2018). Frequency dependence of receiving sensitivity of ultrasonic transducers and acoustic emission sensors. Sensors (Switzerland), vol. 18, no. 11, pp. 1–30.
[18] L, Zhu., B, Zou., S, Gao., Q, Wang., & Z, Jia. (2015). Research on gate valve gas internal leakage AE characteristics under variety operating conditions. 2015 IEEE International Conferences Mechatronics Automation, ICMA 2015, no. c, pp. 409–414.