A Study on Correlation of AE Signals from Different AE Sensors in Valve Leakage Rate Detection

Watit Kaewwaewnoi¹, Asa Prateepasen², and Pakorn Kaewtrakulpong³, Non-members

ABSTRACT

Typically, an AE measurement system consists of sources, test material, couplants, AE sensors, pre-amplifiers, filters, amplifiers, and data acquisition system. However, any useful information from measurements was limited to each AE system. Therefore, this result does not generalize when some components become different.

This paper presents a novel method to make the ratio of AErms spectra of AE sensors in the application of valve leakage rate detection. This method aims at transferring the information between AE inspection systems using different types of sensor by relationship called a transfer function. The spectrum density function/AErms spectra of both wide band (WD) and resonance (R15) AE sensors were studied. The results demonstrated a very good similarity transfer function in various conditions.

Keywords: Acoustic emission, Valve leakage rate, AErms

1. INTRODUCTION

Acoustic Emission (AE) is defined as transient elastic waves generated by a rapid release of energy from intrinsic sources within material [1]. AE inspection is widely used for valve leakage detection applications especially in refineries, petrochemical and nuclear plants due to its ease of use. It can also be used to measure both gas and liquid leakage rate without process interruptions.

Previous Work on using AE inspection in valve leakage measurement has been concentrated on describing characteristic of AE leakage signals and establishing relationship between AE parameters and leakage rate of valve [2-4]. The relation between AE activities and leakage rate at different valve sizes and inlet pressures was also investigated in our previous research [5]. However, the applications of the obtained relationships are limited to systems using the same set of equipment. Changes in some parts of the system especially types of sensors and signal conditioners require costly reinvestigation. Therefore, the main contribution in this paper is an attempt to make the information obtained from one AE inspection system transferable to another. Similar work has been active in the field during the last decade, for example, to find AE artificial sources to calibrate AE systems [6,7] and an attempt to make information transferable from one to other systems in tool wear monitoring [8,9]. Our proposed method makes use of constant “frequency response function” and validates the results by a set of experiments.

2. THEORIES

2.1 Acoustic Emission Measurement

AE system for valve leakage measurement generally contains AE sensors, couplants, pre-amplifiers, filters, amplifiers, and data acquisition system connected to a valve body. Fig 1 shows a block diagram of the signal flow in an AE measurement system.

![Fig.1: Block diagram of signal flow in AE measurement system](image-url)
The AE signals received from transducers are elastic energy waveforms generated from intrinsic sources and propagated through valve body and couple into AE transducers. Typically, piezoelectric transducer type is mostly used and can be classified into two categories; resonant and wideband sensors. Resonant sensor is more sensitive at certain frequencies depending on resonant frequencies of its ceramic piezoelectric crystal. Wideband sensors are manufactured similarly; nevertheless, an energy-absorbing backing material is introduced to damp out predominant frequencies resulting in flatter frequency response.

2.2 Comparison of AE Spectra

In this section, constant frequency response ratio in form of RMS spectrum is presented to make information transferable between systems using different AE transducers. An RMS spectrum is simply the square root of the energy spectrum, also known as spectral density function. In terms of the spectral density function, the transfer characteristics from input source to the output of the sensing instrument is governed by

\[ G_y = |H(f)|^2 \cdot G_x(f) \]  

where the spectral density functions of the input and output are \( G_x(f) \) and \( G_y(f) \), respectively and \( H(f) \) is the frequency response function describing the dynamic of the input signal transmitted through AE sensors. It should be noted that \( G_x(f) \) denotes the AE produced at the source of the leakage by the escaping gas. Fig. 2 shows different signal propagation paths from a common input to two different sensors.

\[ G_y(f) \xrightarrow{H_1(f)} |H_1(f)|^2 \xrightarrow{G_y(f)} G_y(f) \]

\[ G_y(f) \xrightarrow{H_2(f)} |H_2(f)|^2 \xrightarrow{G_y(f)} G_y(f) \]

**Fig.2:** Different signal propagation paths from a common input

Since the same input \( G_x(f) \) is used, their transfer equations can be written as

\[ G_{y1} = |H_1(f)|^2 \cdot G_x(f) \]  

and

\[ G_{y2} = |H_2(f)|^2 \cdot G_x(f) \]

By dividing equation (2) by equation (3), we arrive at

\[ G_{y1}/G_{y2} = |H_1(f)|^2/|H_2(f)|^2 \]

where \( G_{y1} \) is AE output of one AE sensor while \( G_{y2} \) is that of the other. According to equation (4), the ratio \( G_{y1}/G_{y2} \) of the AE spectra output represents the transfer function of both AE sensors.

2.3 Relationship between AE rms and Valve Leakage Rate

For continuous AE signal from both time and frequency domains, the most frequently used AE parameters are the average energy (AE rms) that is the root mean square value of the AE signal. Since Acoustic Emission activity is attributed to rapid releases of energy in the material, the energy content of the acoustic emission signal is related to this energy release. It can be defined as

\[ AE_{rms} = \sqrt{\frac{1}{T} \int_{t_0}^{t_0+T} v^2(t) dt} = \sqrt{\frac{1}{N} \sum_{n=1}^{N} v^2(n)} \]  

where \( v \) is the voltage signal from an AE sensor, \( t_0 \) the initial time, \( T \) the integration time of the signal, and \( N \) the number of discrete AE data within the interval \( T \).

The relationship between AE rms and valve leakage rate is selected as the subject to be transferred to another system in this work. From our previous research [5], AE rms exhibits the relationship with valve leakage rate. The experiment had been conducted using three sizes of ball valve of diameter 1, 2 and 3 inches and inlet pressure between 1-5 bars. An AE sensor with resonant frequency of 150 kHz was selected to detect the signal because its frequency response covered the frequency range of the leakage. The result was investigated and the relationship can be expressed as

\[ \log(Q) = 1.782 \log(AE_{rms}) - 0.543 \log(P) + 0.320 \log(S) - 3.550 \]

where \( Q \) is the leakage rate in ml/sec, \( P \) the inlet pressure in bars and \( S \) the valve size in inches. However, when a part of AE system (e.g. the type of AE sensor) was changed, the previously founded equation is not transferable.

3. EXPERIMENTAL SET-UP

A set of experiments was designed to investigate the transferability of the relationship obtained from a system using one type of transducer to another. Varying in operating conditions including leak size of valve and inlet pressure was also examined. The test system is set up as illustrated in Fig 3. In order to compare and establish the correlation between AE signals obtained from different AE sensors, PAC piezoelectric sensors of wide band (WD) and resonant (R15) types were mounted in each other vicinity at the down stream side of the valve to reduce variation due to spatial difference in the installed locations.
The output signals of R15 and WD sensors are represented by \( G_{y1}(f) \) and \( G_{y2}(f) \), respectively. Since the application of appropriate couplant to minimize energy loss at the interface of workpiece and sensor is one of the most important factors in applying an AE measurement, couplant of the same type (from PAC) was employed in a standard procedure. Signals from both AE sensors were amplified with the same pre-amplifier set at the gain of 60 dB. A band pass filter with a pass band ranging from 100 kHz to 1200 kHz (from PAC) was used as a signal conditioner. The space between AE sensor and pre-amplifier was kept minimal to minimize signal loss in connecting cables. Output signals from the pre-amplifier were fed into the amplifier and analyzer, LOGAN 320, set at gain of 20 dB and were recorded by a real time signal analyzer HP 89410A (with a sampling rate of 10 MHz). The AE spectrum in the frequency span from 0 to 1 MHz was recorded using 401 sample points and was averaged for 500 times. Pencil lead breaks, in accordance to ASTM Standards [10], to verify performance of AE sensor attachment is performed after the installation. An air compressor was used to generate the system pressure which was kept steady by a regulator. The valve leakage rate was determined from differential pressure of a known volume chamber. A high precision pressure gauge with resolution of 0.05 bar was used for monitoring the chamber’s pressure.

In our experiments, artificial leaks from incomplete closure of ball valve are used to simulate the leakage. The tests were conducted by varying inlet pressure from 1 to 5 bars in three valve sizes of 1, 2 and 3 inches respectively. In each result, the curve of the ratio \( G_{y1}/G_{y2} \) was computed.

4. RESULTS AND DISCUSSION

In our previous work, the correlation between AE parameters (AERms) and leakage rate was studied using AE signal received from the AE sensor (model R15). The relation between the leakage rate (ml/sec) and the AERms (mV) of valve size of 1 inch at three different pressures is shown in Fig. 4. The AERms rapidly increases at low leakage rates then gradually at high rates. The AERms also increases with pressure. In addition, the results provided similar trend for the valves of size 2 and 3 inches. Fig. 5 shows the relationship between AERms and the leakage rate at 5 bars of different valve sizes. Analogous experiments using inlet pressures at 1 and 3 bars also revealed similar correlation; however, AE signal reduced with the size of valve. It can be concluded that the important parameters which effect AE signal are valve inlet pressure, valve size and the leakage rate. In order to implement an AE inspection system to measure the leakage rate, an equation to predict the leakage rate using AERms calculated from frequency domain in the range of 100 kHz-1200 kHz, was established as shown in equation (6).

In this research, the AE signals from different sensors were studied to establish the correlation in form of frequency response ratio of RMS spectrums. Fig. 6 presents AERms spectra of the leakage signals from both wide band (WD) and resonance (R15) sensors.

**Fig. 3:** Diagram of experimental set-up

**Fig. 4:** Relationship between AERms and leakage rates of 1 inch ball valve at different pressures

**Fig. 5:** Relationship between AERms and leakage rates of different valve sizes at \( P = 5 \) bar

It can be seen that the shapes of the two AE spectra are similar in most area; however, the signal from R15 type has greater peak AE amplitudes around its resonance frequencies than those of WD. This is due
to the frequency response function of R15 is more sensitive at the frequency of AE released from valve leakage. From our experiment, the curve of the ratio $G_{y1}/G_{y2}$ from AE outputs of various leak sizes for each combination of valve size and inlet pressure was similar. An example of those for a valve size of 2 inches and a constant system pressure of 3 bars is depicted in Fig. 7. In the figure, different leak sizes giving leakage rates ranging from 50 to 100 ml/sec were plotted on the same scale. The results clearly indicate that all curves were close to each other over the whole frequency range from 0-1 MHz. Similar results were obtained for the curve of ratio $G_{y1}/G_{y2}$ when the pressure was varied from 1-5 bars at each pair of valve size and fixed leak size. An example for 2 inch valve is presented in Fig. 8.

From equation (4), the ratio of the frequency response function, corresponding to different sensors should remain the same at any leak sizes and pressures. The results of the ratio curves for the valve of size 1 inch agreed very well to those of the valve of size 2 inches.

$H_1(f)$ and $H_2(f)$ were equally affected by leakage signals. The other is that condition must be maintained at all frequency, 0 to 1 MHz across the spectrum; however, highly improbable.

There were test results showing the curves ratio $G_{y1}/G_{y2}$ of valve of size 3 inches by varying pressure from 1-5 bars at a fixed leak size as shown in Fig. 9. In the figure, it was found that the curves were only tightly closed to the others in the frequency range from 100 - 300 kHz. Therefore, these results can determine the constant scalar value of constant frequency response ratio (the curves ratio $G_{y1}/G_{y2}$) in the range between 100 kHz - 300 kHz that is $813.211$. This value can be applied to convert AE rms from the WD sensor into that from the R15 sensor. However, a new equation was found for the conversion in the range of 100 kHz-300 kHz as

$$\log(Q) = 0.213 \log(AE_{rms}) - 1.71 \log(P) + 0.787 \log(S) - 0.489$$

(7)

where $Q$ is the leakage rate in ml/sec, $P$ the inlet pressure in bars and $S$ the valve size in inches.
From equation (7), the error rate of prediction is between 11.16% and 20.11% for the range of the leakage rate from 40 to 100 ml/sec.

5. CONCLUSION

Correlation of AE signals from two AE systems for valve leakage rate detection application was studied by monitoring AE rms outputs of two AE sensors in various conditions including different combinations of valve leak sizes and inlet pressures. Transfer functions of two AE sensors are calculated and represented by the ratio of frequency responses of the two sensors. This means that we can obtain the transfer function of another sensor from that of previously examined transducer. This is particularly useful since the information obtained from one sensor may be converted into another without having to repeat the experiments. However, the results presented in Fig. 9 showed that the response ratio of the sensors may only be valid in the overlapping pass band of both transducers due to inherit numerical instability of the ratio computation. Nevertheless, the result is still practically useful with the application of AE rms instead of individual frequencies of the whole spectrum.

References


