CHAPTER 4 COMPARISION METHOD OF AE SPECTRA

4.1 Overview

This chapter concerns with proposed comparison method to convert AE information between different AE systems using comparison ratio of AE spectra. This method aims at characterizing the information between AE inspection systems using different types of sensor in application valve leakage rate detection. Since the spectrum density function or AE spectra of both AE sensors have constant frequency response ratios in certain range, Parseval's theorem can be used to converting energy rate or AE signal power (AE_{RMS}^2) between frequency and time domains.

4.2 Background Problem

Typically, an AE measurement system consists of sources, test material, couplants, AE sensors, preamplifiers, filters, amplifiers, and data acquisition system. However, any useful information from measurements is limited to individual AE system. Therefore, the results do not generalize when some components become different.

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 [32, 33, 34, 35]. The relation between AE activities and leakage rate at different valve sizes and inlet pressures level was also investigated in previous researches [33, 35]. 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. Although, the theoretical model to predict the valve leakage rate derived in the previous chapter is also meaningless when AE sensor (R15) used to collect information in this dissertation is changed to other types.

Therefore, the main contribution in this chapter is an attempt to make the information, obtained from one AE measurement system employing AE sensor (R15), transferable to another employing AE sensor (WD) from PAC.

4.3 Comparison Method of AE Spectra

4.3.1 Assumptions and Background Theory

The assumption is that constant frequency response ratio in form of RMS spectrum between different AE sensor systems is presented. This is to construct transferable information using comparison method of AE spectra. 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 of characteristics from input source to the output of the sensing instrument is governed by [72]

$$G_{y1y2}(f) = |H(f)|^2 \cdot G_{x1x2}(f) \tag{4.1}$$

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 dynamics 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. Figure 4.1 shows different signal propagation paths from a common input to two different sensors [72].

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

$$G_{y1}(f) = |H_1(f)|^2 \cdot G_x(f), \tag{4.2}$$

and

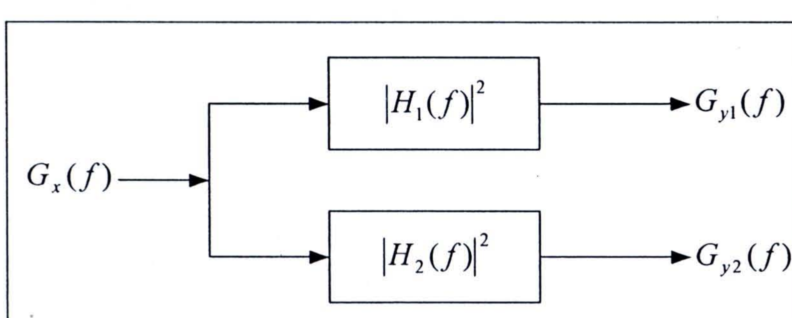

Figure 4.1 Different signal propagation paths from a common input [72].

$$G_{y2}(f) = |H_2(f)|^2 \cdot G_x(f) . \tag{4.3}$$

By dividing Equation 4.2 by Equation 4.3, it arrives at

$$G_{y1}/G_{y2} = |H_1|^2 / |H_2|^2 \tag{4.4}$$

where G_{y1} is AE output of one AE sensor while G_{y2} is that of the other. According to Equation 4.4, the ratio G_{y1}/G_{y2} of the AE spectra output represents the transfer function of both AE sensors.

4.3.2 Experimental Set-up

A set of experiments was designed to investigate the transferability of the relationship obtained from a system using one type of AE sensor to another. Varying in operating conditions including leak size of valve and inlet pressure level was also examined. The test system is set up as illustrated in Figure 4.2.

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 downstream 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 according to the standard procedure [69]. Signals from both AE sensors were amplified with the same preamplifier 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 pressure was varied from 100 kPa to 500 kPa at various test conditions.

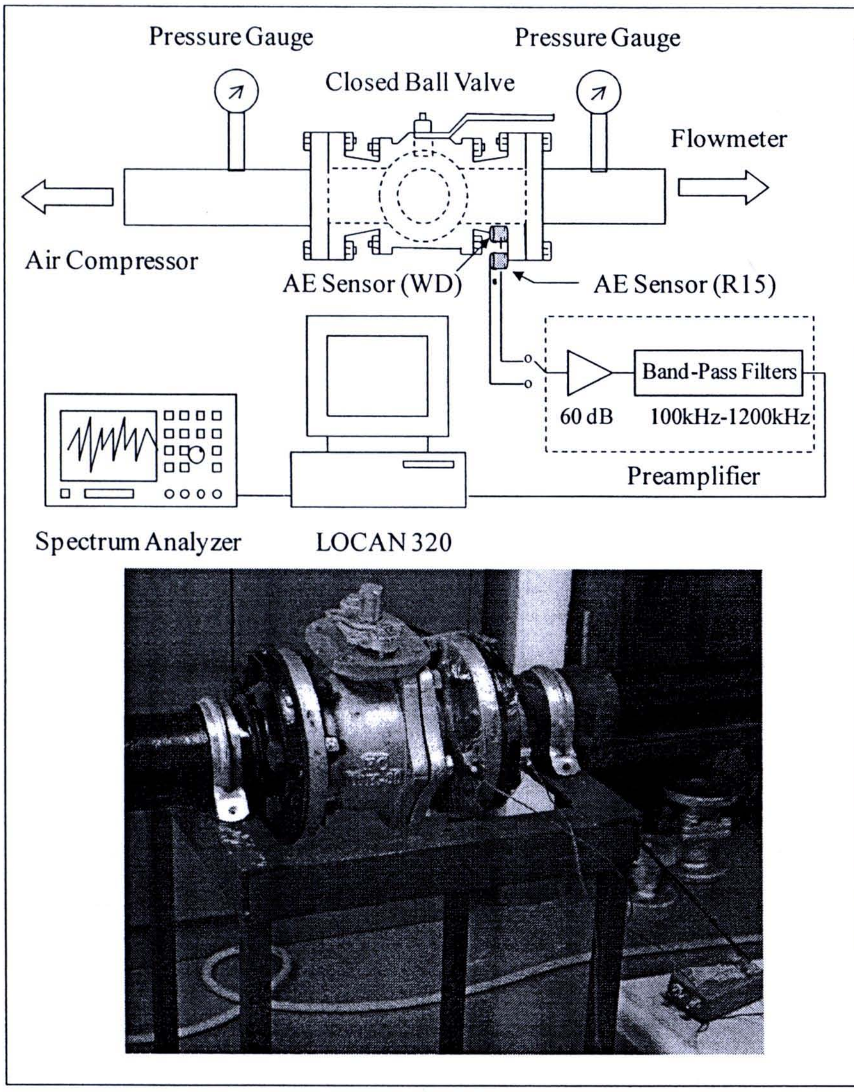

Figure 4.2 Experimental set-up.

4.3.3 Result of Comparison of AE Spectra

In this section, the AE signals from different sensors were studied to establish the correlation in form of frequency response ratio of RMS spectrums. Figure 4.3 presents AE spectra of the leakage signals from both wideband (WD) and resonant (R15) sensors.

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 the valve leakage.

It should be noted that the output signals of R15 and WD sensors are represented by $G_{y1}(f)$ and $G_{y2}(f)$, respectively. An example of those for a valve size of 50.8 mm and a constant system pressure of 300 kPa is depicted in Figure 4.4. In the figure, different leak sizes giving leakage rates ranging from 2.5 to 6.0 l/min 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 to 1 MHz. Similar results were obtained for the curve of ratio G_{y1}/G_{y2} when the pressure was varied from 100 kPa to 500 kPa at each pair of valve size and fixed leak size. An example for 50.8 mm valve is presented in Figure 4.5.

From Equation 4.4 in the Section 4.3.1, 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 25.4 mm agreed very well to those of the valve of size 50.8 mm. These results may arise from two possibilities. The first hypothesis might be that both $H_1(f)$ and $H_2(f)$ were not affected by leakage signals or that both $H_1(f)$ and $H_2(f)$ were linearly affected by leakage signals. The other is that condition must be maintained at all frequencies, 0 to 1 MHz across the spectrum; however, it is highly improbable.

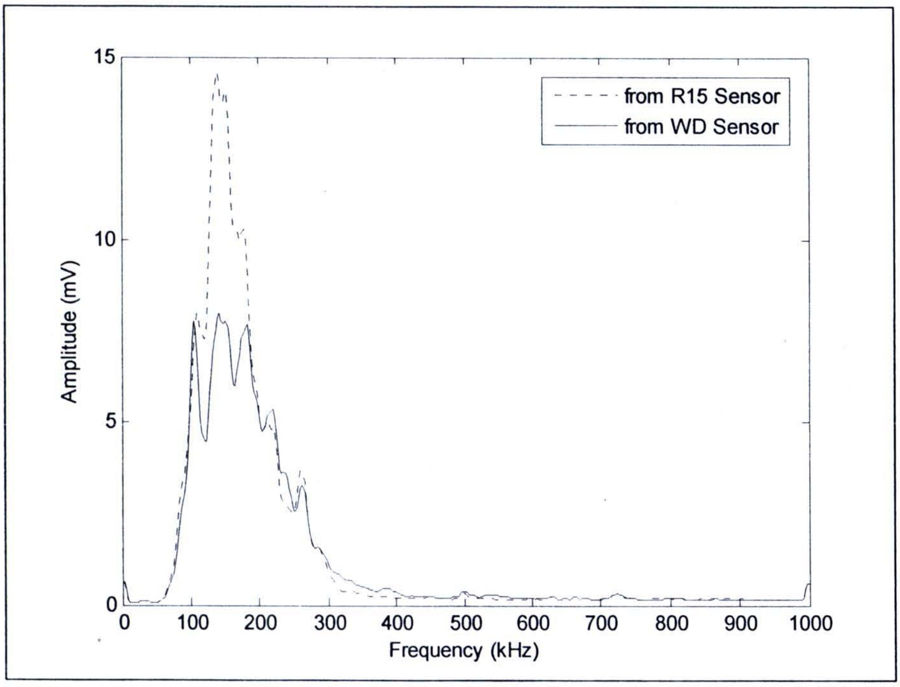

Figure 4.3 AE_{RMS} spectra of the leakage signals.

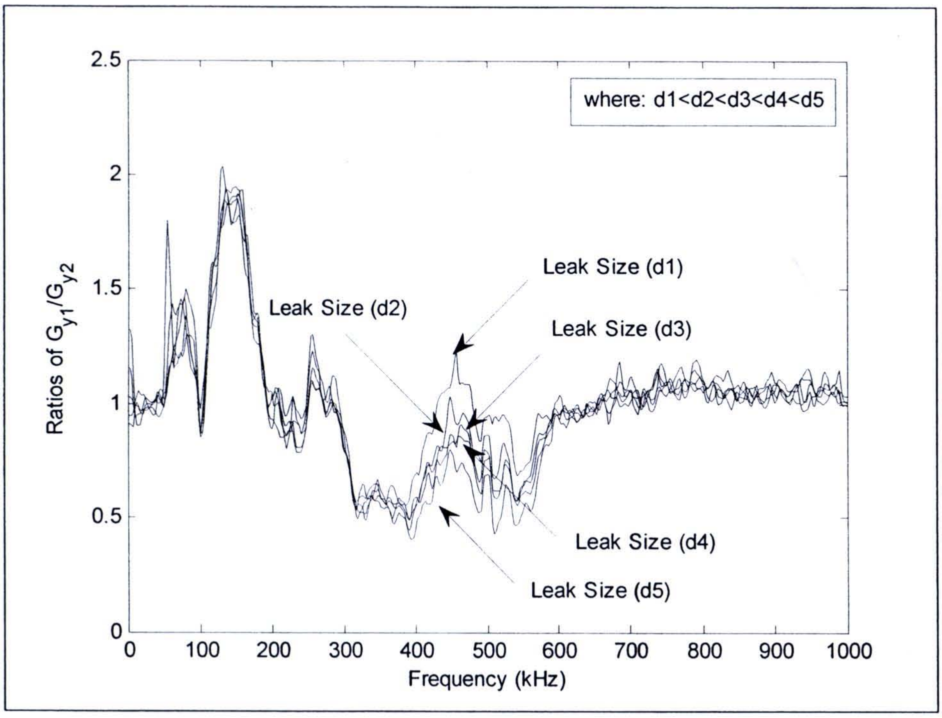

Figure 4.4 The ratios of G_{y1}/G_{y2} for various leak sizes of valve size of 50.8 mm.

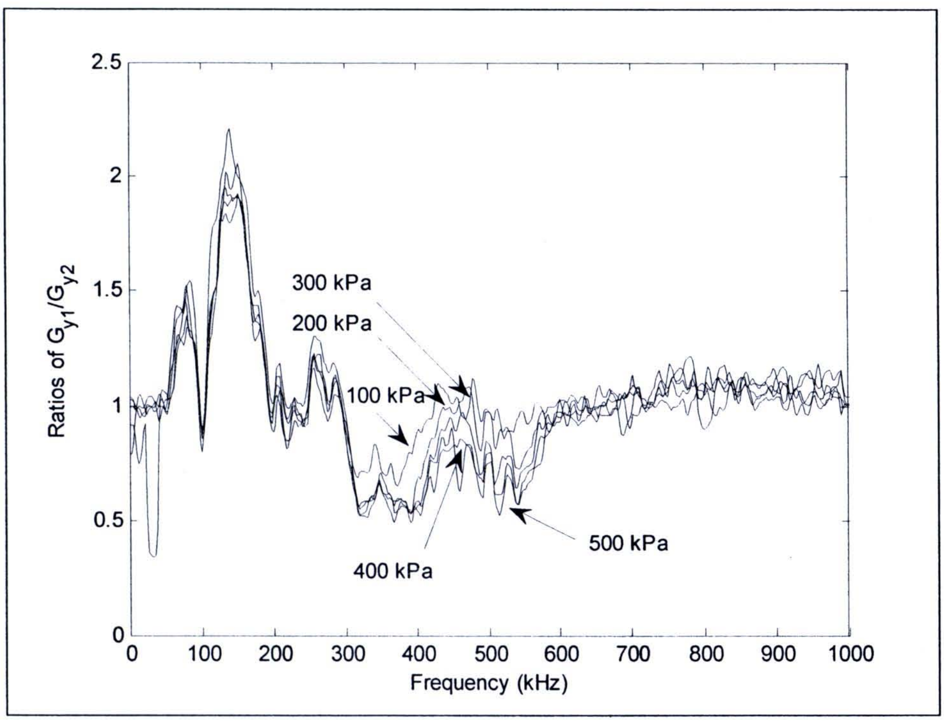

Figure 4.5 The ratios of G_{y1}/G_{y2} for various pressures from 100 kPa to 500 kPa of valve size of 50.8 mm.

There were proved by results showing the curve ratios G_{y1}/G_{y2} of valve of size 76.2 mm by varying pressure from 100 kPa to 500 kPa at a fixed leak size as shown in Figure 4.6. In the Figure 4.6, we found that the curves were only tightly closed to the others in the frequency range from 100 kHz to 300 kHz. Considering the Equation 4.4, it was confirmed that the ratio of two frequency response functions of different systems, hence different AE sensor, was linear only with frequency ranging from 100 kHz to 300 kHz. The result suggests that it is possible to apply this certain frequency range to convert AE_{RMS}^2 from the WD sensor into that from the R15 sensor.

Therefore, these results can be used to determine the constant scalar value of constant frequency response ratio (the curves ratio G_{y1}/G_{y2}), called scaling factor in the range between 100 kHz to 300 kHz. The relationship of AE power both time and frequency domains of AE information using Parseval's theorem will be described in the next section.

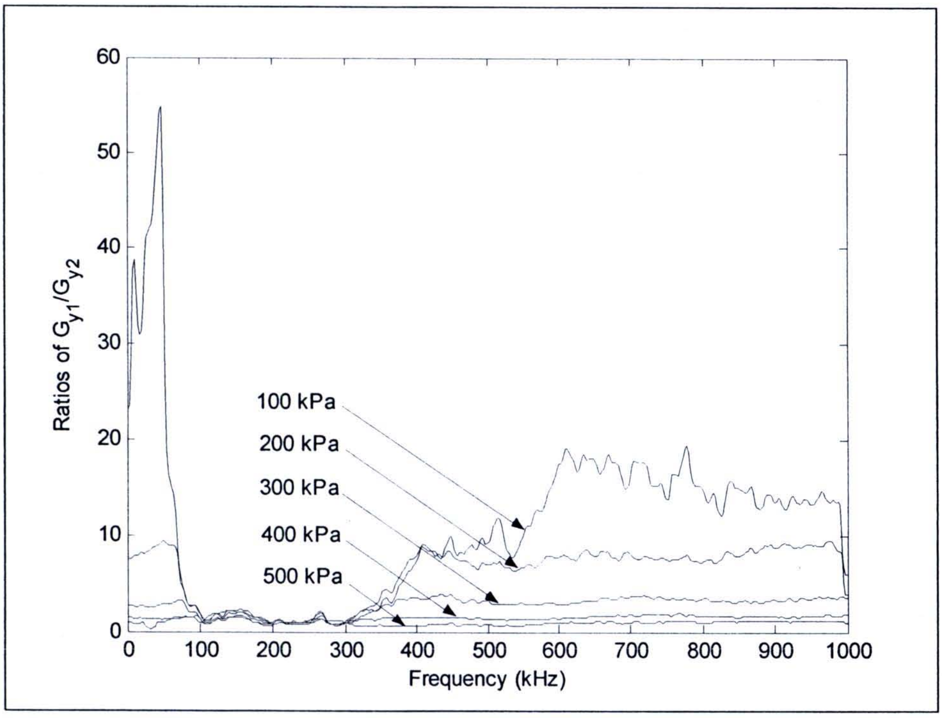

Figure 4.6 The ratios of G_{y1}/G_{y2} for various pressures from 100 kPa to 500 kPa of valve size of 76.2 mm.

4.4 Relationship of AE Power both Time and Frequency Domain

The theoretical model to predict the valve leakage rate in Equation 3.33 is assumed from relation between AE signal power extracted in time domain and sound power generated by valve leakage. However, the Section 4.3.3 was found that the frequency ratios of two different systems within the range of 100 kHz to 300 kHz are significantly similar. Thus, this section presents a method to extent the theoretical model by converting AE signal power extracted in the time domain to AE signal power extracted in the frequency domain using Parseval's theorem.

Since the AE signal from valve leakage was a continuous signal which was of a random type in the time domain as shown in Section 3.5.3, their random nature cannot be described by an explicit mathematical relationship. Therefore, the relevant statistical parameters were introduced to analyze the signal. To extract useful information from this AE data, the Root-Mean-Square (RMS) value was often used to calculate the average energy contained in the raw AE signals. For an AE signal consisting of N samples, $x[0]$, $x[1]$,..., $x[N-1]$, its RMS value was given by [85]:

$$AE_{RMS} = \left(\frac{1}{N} \sum_{n=0}^{N-1} x[n]^2 \right)^{1/2} . \tag{4.5}$$

In addition, parameters measured in the frequency domain were also interesting. These include the peak frequency, magnitude of the dominant frequency component and the energy contained within frequency bands. Such parameters could be obtained through spectral analysis using a Fourier Transform. The power spectral density (PSD) represented the distribution of the signal power over frequencies of raw AE signals. PSD could be computed using the following expression [74]:

$$P[k] = \frac{T_0}{N} |X[k]|^2 = \frac{T_0}{N} \left| \sum_{n=0}^{N-1} x[n] \exp(-j2\pi kn/N) \right|^2 \; ; 0 \le k \le N-1 \tag{4.6}$$

where $P[k]$ is the power spectral density,

$X[k]$ is the Discrete Fourier Transform (DFT) of an AE signal,

N is the number of discrete AE data within the period of time (T_o), and

$x[n]$ is the AE signal voltage in discrete-time system (mV).

In fact, the AE_{RMS} calculated by Equation 4.5 and the AE energy measured in the PSD spectrum were equivalent. According to Parseval's theorem, the time signals, $x[n]$, and its DFT, $X[k]$, satisfy the following equation [88]:

$$T_0 \sum_{n=0}^{N-1} |x[n]|^2 = \frac{T_0}{N} \sum_{k=0}^{N-1} |X[k]|^2 \ . \tag{4.7}$$

Substitution of Equations 4.5 and 4.6 into Equation 4.7 and rearranging it yields

$$AE^2{}_{RMS} = \sum_{k=0}^{N-1} P[k]\Delta F \ . \tag{4.8}$$

In this Equation, $\Delta F = 1/(NT)$ was the discrete frequency sample interval. Notice that the term, AE^2_{RMS}, represented the average power of the signal measured in the time domain, and the term of the $\sum_{k=0}^{N-1} P[k]\Delta F$, which was the integration of the PSD within a frequency range, represented the power measured in the frequency domain. This agreed with Parseval's theorem [89], which was a power computed in one domain equalled the power in the other. In addition, in this work the relationship of AE^2_{RMS} in the time domain and the frequency domain obtained from the experimental results were verified and found to be equivalent as shown in Figure 3.2. Its condition is for ball valve of 50.8 mm diameter at various leakage rates.

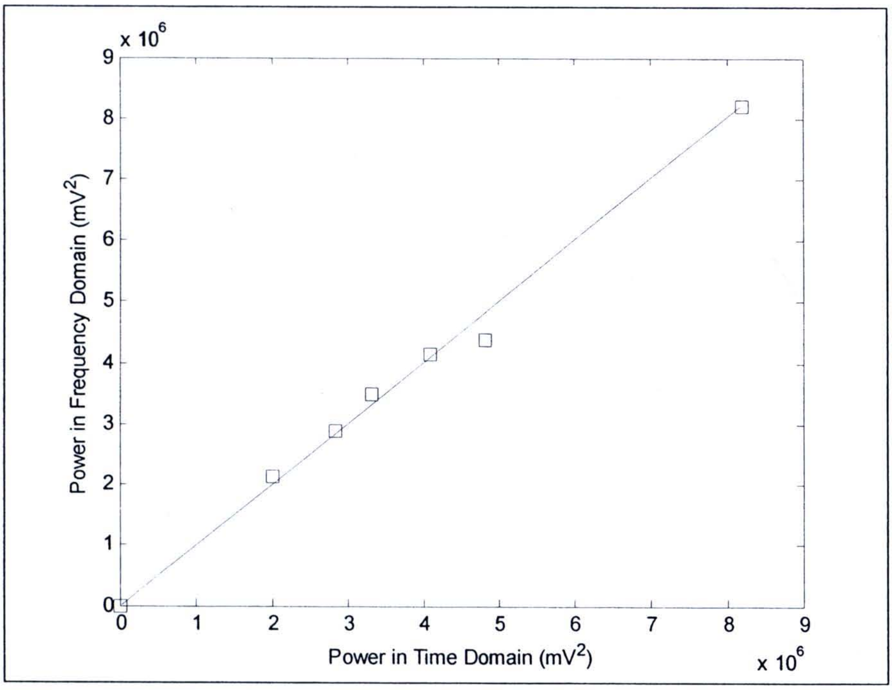

Figure 4.7 Equivalence of power between time and frequency domains from experimental result.

Therefore, it may be confirmed that energy rate-based AE parameters, measured in the time domain (AE_{RMS}^2) or in the frequency domain ranging from 100 kHz to 300 kHz (calculated by Equation 4.8), were very suitable to represent the AE signals induced by internal valve leakage and could be transferred to one another.