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SNR Improvement of AE Signal for Detection of Gas Leak from Tubes under Vibratory Environment

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Abstract Detection of gas leak from a tube is a very important issue in the quality control of machines such as the heat exchanger of an air-conditioner, because leakage of operating gas directly reduces the performance of machines. The acoustic emission (AE) method is a common way to detect leak of gas, however its application under the environment of mechanical vibration is restricted since most AE detectors are very sensitive to external vibration noise. In order to overcome this problem, we propose a method based on the mode analysis of the Lamb wave. In this method, the dominant Lamb mode and its frequency are found first, and then a proper band-pass filter is used to retain only this frequency component. In this way, we could improve the SNR (signal-to-noise ratio) of AE signal generated by gas leak from the tube even under vibratory environment.

Keywords: AE (Acoustic Emission), Gas Leak, Tube, Lamb Mode, SNR Improvement.

1. Introduction

Detection of gas leak from tube is a very important issue in the quality control of machines such as the heat exchanger of an air-conditioner, because leakage of operating gas directly reduces the performance of the machines. The acoustic emission (AE) method is a common way to detect this kind of gas leak (Lord et al., 1977; Lee, 2004), however its application to a tube in mechanical vibration is restricted since most AE detectors are very sensitive to external vibration noise. In order to overcome this problem, we propose a method to detect the pure AE signal generated by the gas leak by using a band-pass filter that is designed based on the mode analysis of Lamb waves in thin tubes.

The thin tube is a good wave-guide, so there must be a type of guided wave (Lamb wave) characteristics in the propagating AE waves in the tube, as seen in thin plates (Yoshihiro et al., 1998; Guo et al., 1996). This Lamb wave may have multiple modes that can be excited at the same time; yet, each mode possesses different frequency-velocity combination (Rose, 1999). Also there may be dominant modes and frequencies for a given structure of tube. Thus we analyzed AE signals in the frequency domain to find the dominant Lamb mode and frequency first, and then designed a band-pass filter to detect only this mode component. By using this filter we can improve the SNR of AE signal and the detectability of minute gas leak under the environment of mechanical vibration.

The effectiveness of this method is verified through several experiments. A pencil break test on a normal tube without leak was carried out first to find the dominant Lamb mode. Next, AE signals produced by a gas leak were analyzed to identify the general characteristics and to

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reconfirm that the dominant frequency component corresponds to the Lamb mode found in the previous test. For this, two kinds of specimen were prepared: One was a prototype tube specimen with an artificially drilled through-hole and the other was a fatigued specimen with a fatigue crack. Finally, we designed a band-pass filter to detect only the dominant Lamb mode component. In order to demonstrate the filtering capability, AE signals from the fatigue crack in both cases, with and without external vibration, were compared, and the correlation of the RMS value of the AE signal obtained in the vibratory environment with gas leakage was examined.

2. Configuration of AE Detection System

Fig. 1 shows the configuration of experimental apparatus used to acquire AE signal produced by the leak from the tube specimen. A high sensitivity AE sensor (VS30, Vallen) is used to detect the AE wave propagated through the tube, whose frequency band is 20-80 kHz. In order to assure wide contact between the flat sensor surface and the round tube surface, an acrylic shoe is inserted. A gas detector (Gascheck3000, Ion Science) measures the leak rate of gas: Helium gas is used as the operating gas. The pressure inside the tube is controlled by the static pressurizer within the range of 0-3 MPa.

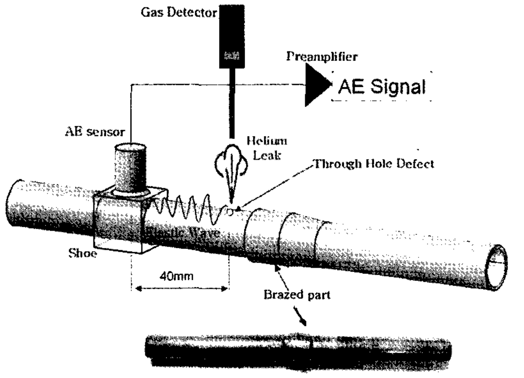


Fig. 1 Configuration of AE experimental apparatus with a picture of specimen

In the experiments, prototype copper tubes fabricated according to the manufacturing process for heat exchanger of an air-conditioner were used as specimens. The diameter and thickness are 16 mm and 1.24 mm, respectively. Two kinds of leak specimen were prepared: One with an artificially drilled through-hole (diameter d = 70 ㎛) and the other with a fatigue crack.

3. Lamb Mode Analysis

In order to apply the AE method effectively, we have to identify the characteristics of AE signal that depends on the propagation medium as well as the leak source, since the AE wave generated at the leak source propagates through the tube as a kind of elastic wave.

Wave propagation in a thin tube has unique characteristics, as a so called guided wave or Lamb wave that has multiple modes with different frequencies and velocities. Also there may be dominant modes and frequencies for a given structure of tube. Thus we investigated the dominant Lamb wave mode on the basis of dispersion curve for the tube specimen used, and tested the AE signal produced by a pencil break.

In order to analyze the frequency components we took the Fourier transform in short overlapping time intervals, the so called STFT (short time Fourier transform) (Kim et al., 2006). Fig. 2 shows the results: (a) is the time signal, (b) is the STFT (short time fourier transform), and (c) is a plot of the transformed data as a map of amplitude with respect to frequency and time, which can directly be compared with a theoretical group velocity dispersion curve. From these, we can see that most of wave energy is concentrated within the range of 50-60 kHz (indicated by a circle in (b)) and this frequency band component corresponds to the lowest longitudinal Lamb mode L(0,1). This means that the use of 50-60 kHz band-pass filter would be useful to detect only this mode of AE signal in the noisy condition.

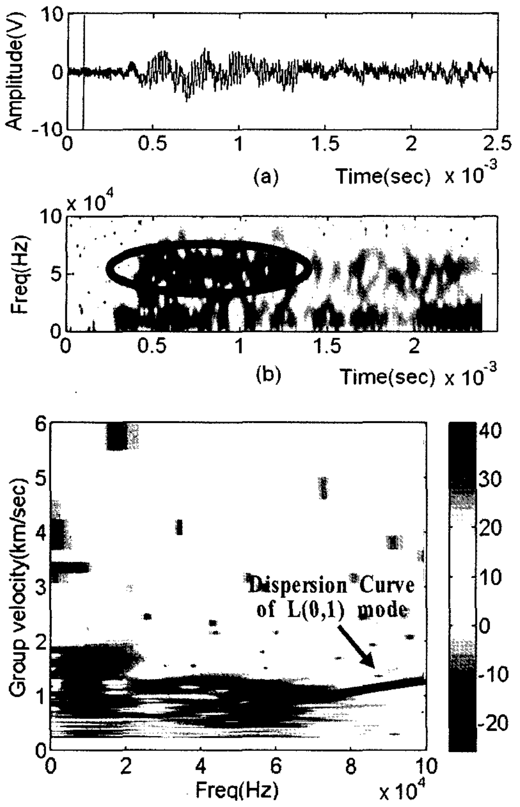


Fig. 2 Mode analysis of AE signal obtained from the pencil break test

4. Experimental Results for Drill-Holed Specimens

Next, in order to identify general characteristics of AE signals produced by gas leaks and to reconfirm the dominant frequency component found in the previous section, two kinds of specimen were tested; one was the prototype tube specimen with an artificially drilled through-hole defect and the other was a fatigued specimen with a fatigue crack.

Fig. 3 shows an AE signal produced by gas leak from the drilled hole (diameter d = 70 ㎛), and Fig. 3(a) shows the background noise signal obtained when there is no leak. We can see a continuous waveform that is the general pattern of AE signals produced by gas leak. Also we can see clear difference in amplitude of signals between the cases of leak and no leak. In order to compare the level of AE signal we will use the RMS value that is commonly used for the quantification of continuous AE signals.

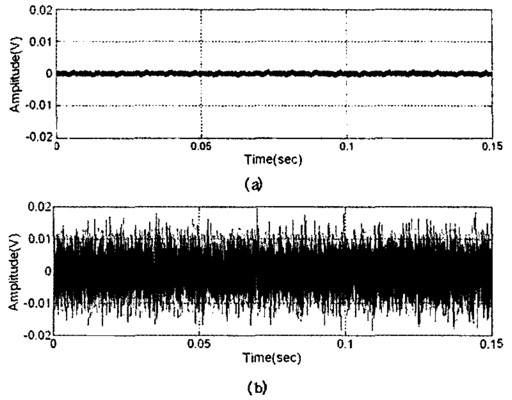


Fig. 3 Typical AE signals obtained for the case of (a) no leak and (b) leak under internal pressure of 1 MPa

Fig. 4 shows the frequency spectra of AE signals obtained as the internal pressure increases from 0.2 MPa to 0.8 MPa, where an increase of internal pressure leads to an increase of leak rate. We can see that 50-60 kHz band is the most dominant and its magnitude increases as the pressure increases. This verifies the result of the earlier mode analysis as well as the fact that 50-60 kHz band signal is directly related to gas leak.

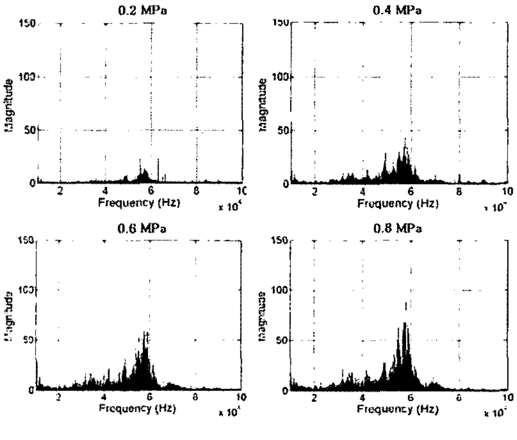


Fig. 4 Frequency spectrum of AE signal when the internal pressure varies from 0.2 MPa to 0.8 MPa

5. Experimental Results for Fatigue Crack Specimen

An accelerated fatigue life tester simulating the loading condition for a heat exchanger tube in an air-conditioner was used to induce a penetrating fatigue crack in the specimen. The crack was straight in the circumferential direction and its length was about 6.5 mm.

AE signals in this case were also continuous, similar to those obtained from the drill-hole leak. As for the frequency information, 50-60 kHz band is still dominant, as shown in Fig. 5 that shows the frequency spectra of AE signals obtained from the fatigue crack as the internal pressure is increased. The magnitude of the spectra in this frequency band increases as the internal pressure increases. This means that our previous result of mode analysis is also valid in the real fatigue crack leak.

In the final experiment, a 50-60 kHz narrow band-pass filter is adopted to detect only the dominant Lamb mode AE signal. Its usefulness is demonstrated in Fig. 6, which shows the AE signals obtained under vibratory environment. We can see the big amplitude of AE signal in (a) even though there is no leak. Compared to this, the signal in (b) obtained after inserting the filter shows that the vibration-induced noise disappeared. The signal in (c) is for the case of leak (the internal pressure is 0.4 MPa), which shows a clear AE signal produced by the leak with the vibration noise filtered out.

Fig. 7 shows the filtered AE signals under the vibratory environment as the internal pressure is increased, and Fig. 8 shows the relationship between the AE RMS value after filtering and the internal pressure. We can see clear time signals in Fig. 7 and good correlation of AE RMS to the leak in Fig. 8. From these, the effect of filtering was confirmed, and consequently it may be stated that we can improve the SNR (signal-to-noise ratio) of AE signals produced by gas leaks from tubes even under the vibratory environment.

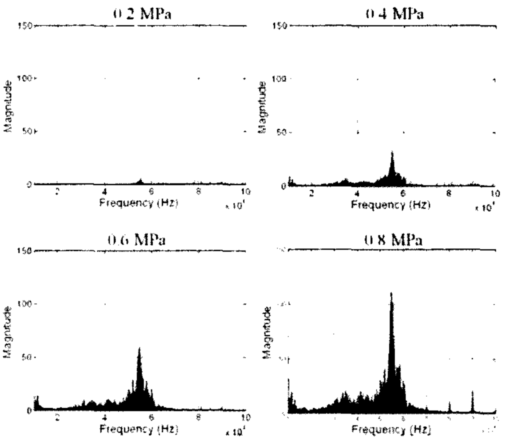
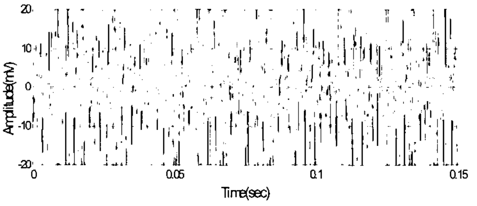
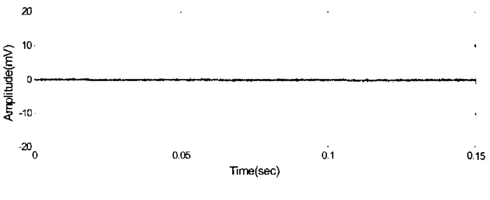


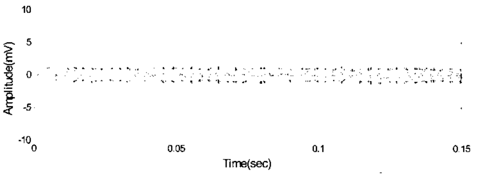
Fig. 5 Frequency spectra of AE signals from 6.5 mm fatigue crack for various internal pressures



(a) Before filtering AE signal for no leak with vibration noise

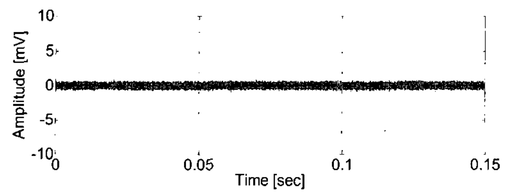


(b) After filtering the signal in (a)

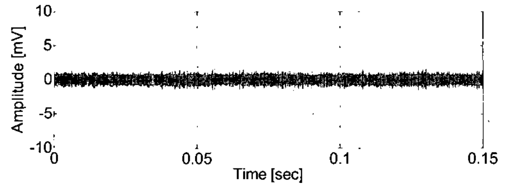


(c) After filtering AE signal for leak with vibration noise

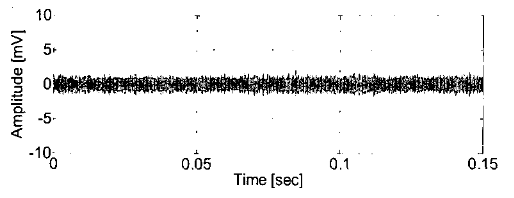
Fig. 6 AE signals under vibratory environment, showing the effect of band-pass filtering



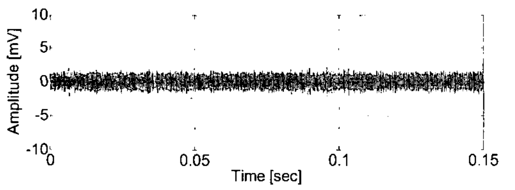
(a) 0.2 MPa



(b) 0.4 MPa



(c) 0.8 MPa



(d) 1.0 MPa

Fig. 7 Filtered AE signals under vibratory environment as the internal pressure increases

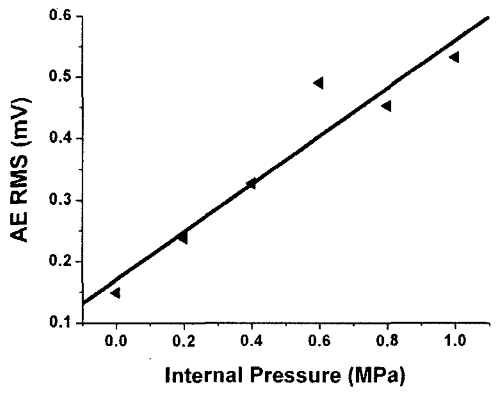


Fig. 8 AE RMS versus internal pressure (with band-pass filter)

6. Conclusion

We have considered the AE method for the monitoring of gas leaks from fatigue cracks of heat exchanger tubes in vibratory environment. The characteristic Lamb mode for the given geometry of specimen was analyzed prior to the AE application to design a narrowband-pass filter that enables to detect only the dominant Lamb mode component. The feasibility of this method was investigated through experiments using prototype specimens with leaks. Two kinds of leak sources were tested: One with an artificially drilled through-hole and the other with a fatigue crack. AE signals showed continuous waveforms which are typical of those observed at gas leaks, and hence the RMS value was used to decide the level of AE signals.

50-60 kHz frequency band was very dominant in the AE signals obtained from both specimens, and from the Lamb mode analysis it was found to correspond to the lowest longitudinal mode propagating through the thin copper tube. However, the dominant mode or the dominant frequency component may be different for different material or different dimensions of tube. Thus, when we apply the AE method to gas leak of thin tubes, one should analyze the AE mode first to identify the dominant mode or the dominant frequency component and then use a band-pass filter designed to detect only this dominant component. In the present case, by using a thus designed narrowband-pass filter, we could improve the SNR of AE signals under the environment of external vibration, and the RMS value of the AE signals showed good linear correlation with the gas leak rate.

Acknowledgments

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