A Study on Acoustic Signal Processing Technique for Detecting Small Leak of Piping System

D.-B. Yoon[1], S.-S. Moon[1], and B.-S. Yang[1]

[1]*Nuclear Convergence Technology Development Division, Korea Atomic Energy Research Institute, 111, Daedeok-Daero 989 Beon-Gil, Yuseong-Gu, Daejeon, 34057, Korea*

yoondb@ kaeri.re.kr
mss@kaeri.re.kr
bsyang@kaeri.re.kr

ABSTRACT

The objective of this work is to develop a signal processing technique for detecting small leak of piping system in a noisy environment. For this purpose, as algorithms for enhancing the leak detection capability, a small leak detection algorithm were developed by using time-spatial characteristics of the measured acoustic signal. The leak detection capability of the developed algorithm is verified by experiments and numerical simulations. It is expected that the developed small leak detection algorithm can be utilized for leak detection of piping system of a power plant.

1. INTRODUCTION

The importance of leak detection of piping system in a power plant of Korea is being emphasized as the pipes of the power plant are more than 20 years old. Various leak detection methods such as the pressure wave detection technique, the ultrasonic guided wave technique, the thermography method, and the process model-based method have been proposed and implemented over the past years [Billman (1984), Iserman (2011), Fuchs (1991)].

Figure 1. Pipe wall-thinning accident of Mihama plant.

The acoustic (vibration) detection method is one of the most commonly used methods for leak detection of piping system. A leak from a pipe generates a leakage signal, which can be used for leak detection. The acoustic detection technique can be successfully applied when the leakage signal has a high signal-to-noise-ratio (SNR). However, in case of a power plant, lots of machinery is installed and continuously operated without a break. The measured signals obtained from the acoustic sensors may contain background noise and machinery noise components as well as a leakage signal component. Since the effectiveness of the acoustic detection technique is largely influenced by the background noise, in the case of a power plant, the acoustic detection technique can be problematic for detecting leaks.

The objective of this work is to develop a signal processing technique for detecting small leak of piping system in a noisy environment. For this purpose, a small leak detection algorithm were developed by using time-spatial characteristics of the measured acoustic signal. Then, the validity of the proposed method is verified by performing experiments.

2. SMALL LEAK DETECTION METHOD

The acoustic field ($p(\bar{r},t)$) due to various sound sources can be express as

$$p(\bar{r},t) = \int G(\bar{r}|\bar{r}_s,t)Q(\bar{r}_s,t)\,\mathrm{d}\bar{r}_s \qquad (1)$$

where $G(\bar{r}|\bar{r}_s,t)$ represents green's function from source location ($Q(\bar{r}_s,t)$) to acoustic sensor location ($\bar{r}$).

The auto-correlation function of the signal $p(\bar{r},t)$ is obtained by [Bendat (1986)]

$$R(\tau) = E\lfloor p(\bar{r},t)\,p(\bar{r},t+\tau)\rfloor \qquad (2)$$

where τ is the lag of time, and $E[\ ]$ is the expectation operator.

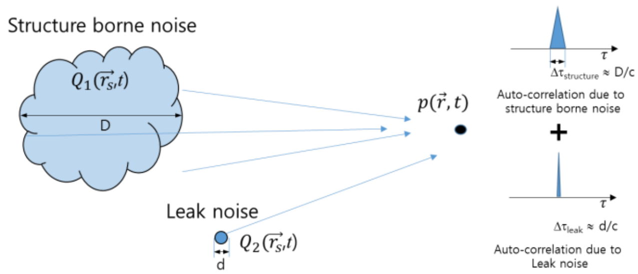


Figure 2. The acoustic pressure and auto-correlation due to acoustic sources.

Since the auto-correlation function of the acoustic signal can be expressed as a convolution of the time characteristics ($Q(t)$) and spatial characteristics ($Q(\vec{r}_s)$), the auto-correlation function of the measured sound can be classified as shown in Table 1. It is well known that the leak signal can be modeled as a random signal. The main idea of this work is that the measured sound of the small leak can be represented as a delta function shape in the auto-correlation domain. Therefore, we can separate the small leak component($\Delta\tau_{leak}$) from structure-borne noise component by two method. The first one is to use high-pass filter in the τ domain. The second one is to use wavelet transform as shown in Figure 3.

Table 1. The auto-correlation functions due to various sound sources

Time Characteristic / Spatial Characteristic	Random Signal	Periodic Signal
Small Leak		
Structural Vibration		

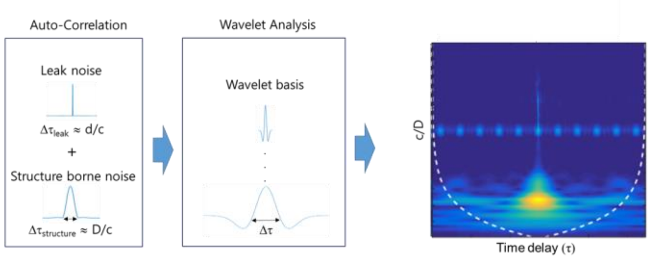
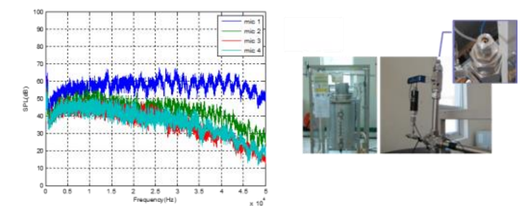


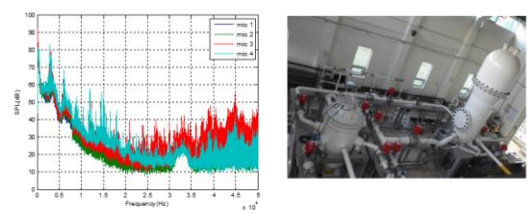
Figure 3. Separation of the small leak component from structure-borne noise component.

3. EXPERIMENTAL RESULTS

An experiment has been performed to investigate the validity of the proposed technique for leakage detection in a noisy environment. Figure 4 represents the experimental setup and measured sound pressure level of the leak signal and pump operation noise.



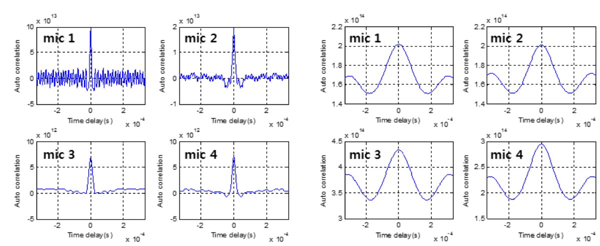
(a) small leak signal



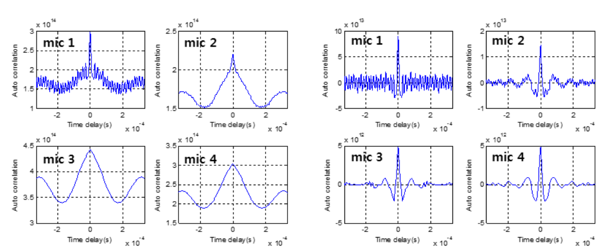
(b) pump operation noise

Figure 4. Measured sound pressure level of the leak signal and pump operation noise.

Figure 5 shows the auto-correlation function due to small leak and pump operation, and Figure 6 shows the wavelet transform of the measured auto-correlation function due to small leak in the presence of structure-borne noise (pump operation).



(a) small leak signal (b) pump operation



(c) small leak + pump operation (d) filtered signal

Figure 5. Auto-correlation function due to small leak and pump operation (experiment).

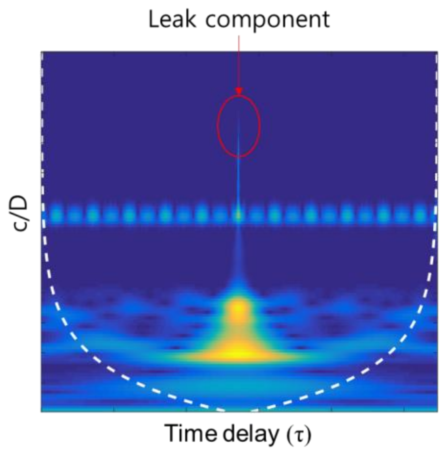


Figure 6. Wavelet transform of the small leak signal in the presence of structure-borne noise (experiment).

It is noteworthy that even in a noisy environment, the proposed method can effectively detect the small leak component as shown in Figure 5(d) and Figure 6.

4. CONCLUSION

The objective of this work is to develop a small leak detection method in a noisy environment. For this purpose, a leak detection technique that can effectively extract the small leak component from the machinery noise environment was proposed. Also, experiments were carried out to verify the validity of the proposed method. The experimental results demonstrate that even in a noisy environment, the proposed method can provide more reliable means for detection of the small leak. It is expected that the proposed method can be utilized for leak detection of piping system in a noisy environment.

ACKNOWLEDGEMENT

This work was supported by the National Research Council of Science & Technology (NST) grant by the Korea government (MSIP) (No. CRC-15-05-ETRI).

REFERENCES

L. Billman et al., (1984) Leak Detection Methods for Pipelines. *Proceeding of the 9th IFAC Congress*, Hungary.

R. Iserman, (2011) *Fault-Diagnosis Applications: Model-based Condition Monitoring*, Chapter 7, Springer.

H. V. Fuchs, (1991) Ten Years of Experience with Leak Detection by Acoustic Signal Analysis. *Applied Acoustics*, vol. 33, pp. 1-19.

J. S. Bendat and A. G. Piersol, (1986) *Random Data*, Wiley.

BIOGRAPHIES

D.-B. Yoon received his M.S. and Ph. D. degrees in mechanical engineering from the KAIST (Korea Advanced Institute of Science and Technology), Korea, in 1993 and 1998, respectively. Since 2000, he has been a senior & principal researcher at the Korea Atomic Energy Research Institute. His current research interests include development of condition monitoring systems for a nuclear power plant, and the development of signal processing technique for analyzing vibration and noise of the industrial structures.