

A Source Localization of Valve Leakage in a Nuclear Power Plant

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1. Introduction

There are many valves and pipes in a nuclear power plant. If water leaking from a pipe or valve, it is difficult to find the location of leakage. This is because the water under very high temperature and pressure change to steam in air, then the steams are invisible. Since there are too many valves, it is impossible to identify the leakage using an accelerometer. In this paper, we proposed a source localization method of valve leakage in a nuclear power plant using microphone array.

Conventional methods; for example, beamforming, and the methods based on eigen structure analysis[1], to identify noise sources assume that noise sources are located at exterior field and therefore reflected waves received at the microphone array can be neglected. However, if we want to do the sources that are located where the reflected waves no longer negligible, then those methods have to do somehow modified so that they can express the reflected waves effects on the identification.

The main objective of this paper is to identify noise sources in reverberant field. Candidate methods to identify noise sources in this case can be classified in two kinds; One is what is based on beamforming method [1], the other is what is utilizing the technique of acoustic holography. The beamforming method has advantage to the other methods. It uses less microphone.

The beamforming method defines the following beam power

$$\begin{aligned} \text{Power} &= \mathbf{W}^H E[\mathbf{P}\mathbf{P}^H] \mathbf{W} \\ &= \mathbf{W}^H \mathbf{R} \mathbf{W} \end{aligned} \quad (1)$$

where \mathbf{W} is a scan vector (weighting vector), \mathbf{P} is the pressure vector over the microphone array, \mathbf{R} is a correlation matrix, E stands for expectation, M is the total number of microphone and H is the Hermitian.

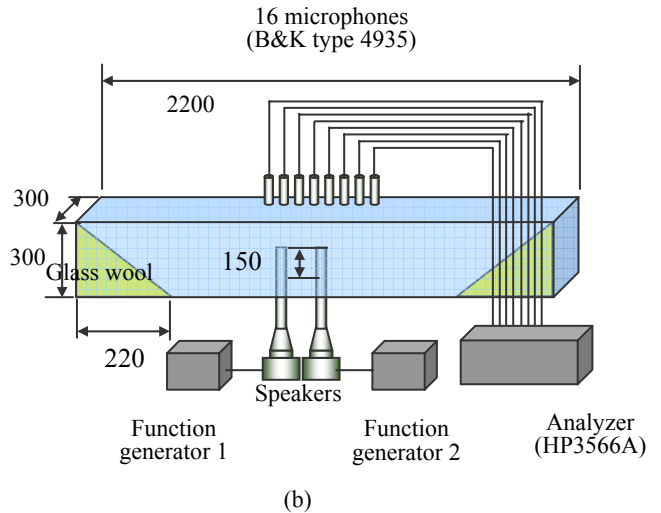
If noise sources are located at far enough so that the waves fronts can be regarded as planar, then the scan vector for Eq. (1) has to be what is based on planar wave model. However, if the measurement has to be closer to the sources, then the scan vector has to be what is based on spherical wave model[2]. This is because the beam power essentially exhibits how well the selected scan vector resembles the measured pressure field. Therefore the quality of identification primarily determines by the goodness of the scan vector. Therefore, if the sources are in the reverberant field, then the scan vector has to be chosen in such a way that it cope with the reverberant field.

2. Source identification in a rigid wall enclosure

To identify noise sources in an enclosure, we have to add the reverberation effects on the scan vector. A simple model, which can mimic the enclosure sound field, can be expressed as the sum of the rigid wall modes.



(a)



(b)

Figure 1 Experimental setup for the source identification in the duct with rectangular section. (a) picture, (b) schematic experimental setup

To test its applicability we made a duct, which was made of an acryl. The size is 0.3m in width and 0.3m of height and 2.2m long. Fig.1 (a) and (b) show the beam power distributions that are obtained by using the conventional scan vector and using the scan vector of Eq. (2). Results show that conventional beamforming method give unacceptable error. However, the beam power by using the scan vector of Eq. (2) shows the dominant peaks around the true sources. These results indicate that the method is quite applicable to identify sources in the rigid wall enclosure.

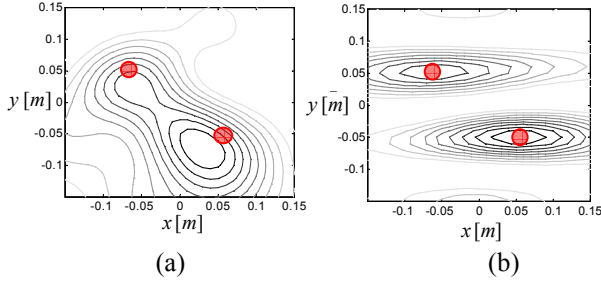


Figure 2: Beam power distribution in the acryl duct, source frequency =2kHz, true source locations $(x_1, y_1)=(-0.06m, 0.05m)$, $(x_2, y_2)=(0.06m, -0.05m)$. (a) using conventional scan vector which is expressed by a spherical wave model. (b) using the scan vector which is expressed as the sum of the rigid wall modes.

3. Source identification in an enclosure with random reflections

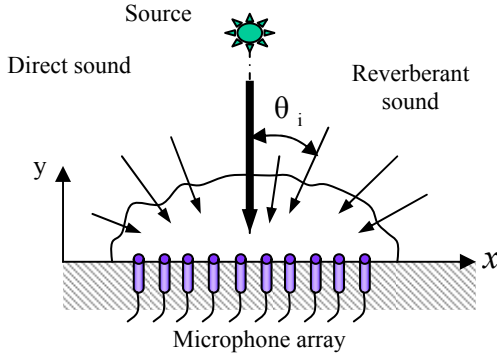


Figure 3: Reverberant field in an admittance wall

If random reflections occur in an enclosure, the scan vector of Eq. (1) is no longer valid. This is simply because the scan vector does not well express the corresponding physical circumstances; random reflections. Instead, we can try the scan vector as the sum of plane waves with random incidence and magnitude as shown in Fig. 2. The pressure distribution with respect to space for a selected frequency can be expressed as

$$p_m(x) = A \frac{e^{jkr_m}}{r_m} + \sum_{i=1}^{\infty} B_i e^{jkx \sin \theta_i} \quad (2)$$

The A is the magnitude of direct sound, and r_m is the distance between source and the m -th microphone. Also B_i and θ_i are the magnitude and phase of the i -th plane wave respectively.

Then, its power can be written as follows.

$$\begin{aligned} \text{Power} &= \mathbf{W}^H \mathbf{P} \mathbf{P}^H \mathbf{W} \\ &\cong \mathbf{W}^H \mathbf{S} \mathbf{S}^H \mathbf{W} + \xi \end{aligned} \quad (3)$$

where, ξ is the total power of the reflections. The first term of the right hand side of Eq. (5) means the beam power of direct sound and the second term is that of reverberant field. Eq. (5) implies that reverberant

fields only increase constant beam power at overall position without changing estimated source locations as illustrated in Fig. 3. This is simply because the random reflection in space means spatially white noise.

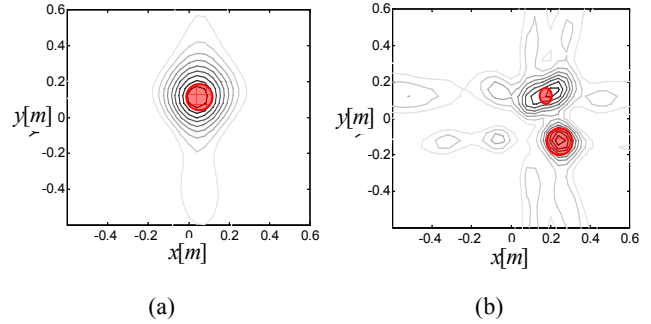


Figure 4: Source prediction by using Eq. (5). (a) Single Source : frequency 9.3kHz, location $(x,y) = (0.06m, 0.085m)$, (b) Incoherent Sources : frequency 19.9kHz, source location $(x_1, y_1) = (0.25m, -0.08m)$, $(x_2, y_2) = (0.166m, 0.152m)$

To verify the reverberant model, the experiment was also performed in the water tunnel that has unknown impedance walls. The tunnel's width and height are 1.2m and 1.2m respectively. Results show that the model (Eq. (3)) well predicts the true source locations.

4. Conclusion

We have proposed the method that can identify the leakage location in the nuclear power plant. The scan vectors can well cope with the reverberant sound field and source signal. The highlight is that the wall reflections can be considered as a spatially white noise, therefore does not degrade the method's ability to find the source locations. This means that only signal to noise ratio in wave number domain determines the source identification performance.

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