資料番号：15－７

技術報告

Development of Microphone Leak Detection Technology in Fugen Nuclear Power Plant

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Development of Microphone Leak Detection Technology in Fugen Nuclear Power Plant

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耐高温用マイクロフォンを用いて１m^3/h～500m^3/hの漏えいを検出するための検出手法がサイクル機構によって独自に開発された。ここで報告する「ふげん」における開発は，同様のマイクロフォンを用いた手法により微小リークを早い段階で検出することを主眼にしている。特に，入口管に対して0.2gpm（0.046m^3/h）の漏えいを目標検出能力に選定し，さまざまな評価手法を用いて検出感度及び漏えい位置の検出精度評価を行い，目標としたこの条件を満たせ得るかどうかの評価を実施してきた。この研究を通じて，微小漏えいを検出し，位置同定を行ない得ることを実証した。検出感度と位置検知精度を改善するための手法として，確率論的な漏えい検知アリゴリズムと多チャンネルの漏えい位置ベースの検知アルゴリズムが提案された。

A method of leak detection, based on high-temperature resistant microphones, was originally developed in JNC to detect leakages with flow rates from 1m^3/h to 500m^3/h. The development performed in Fugen and reported here focuses on detection of a small leakage at an early stage by the same microphone method. Specifically, for the inlet feeder pipes the leak rate of 0.2gpm (0.046m^3/h) has been chosen as the target detection capability. Evaluation of detection sensitivity and leak localization accuracy was conducted based on various analysis methods in order to check the capability of the method to satisfy this requirement. The possibility of detecting and locating a small leakage has been demonstrated through the research. The probabilistic detection algorithm and multi-channel location-based detection are proposed in order to improve both the detection sensitivity and the localization accuracy.

キーワード

漏えい検知システム，音響モニタリング，漏えい位置検知，マイクロフォン，冷却材漏えい，漏えい音，音の減衰，背景騒音，相互相関関数，新型転換炉ふげん

Leak Detection System, Acoustic Monitoring, Leak Localization, Microphone, Coolant Leak, Leakage Sound, Sound Propagation Attenuation, Background Noise, Cross-Correlation Function, ATR Fugen

1. INTRODUCTION

A method of leak detection, based on high-temperature resistant microphones, was originally developed in JNC for an Advanced Thermal Reactor (ATR) in order to detect leakages at the inlet feeder piping. In a previous work[1)], leak rates from

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1m^3/h to 500m^3/h were investigated through series of experiments in O-arai Engineering Center and a feasibility study on ATR-prototype reactor Fugen (Fig.1A) using a first generation microphone system.

The next generation system was developed for the inlet- and outlet-piping of the RBMK reactor within the framework of the Japan-Russia cooperation project founded by the Japanese Government[2]. The RBMK is a graphite-moderated, light-water-cooled, pressure-tube-type reactor. In spite of the different design, both the RBMK reactor and Fugen have a similar cooling system, which makes it possible to develop a common approach to leak detection. The microphone leak detection system was installed and successfully tested on Leningrad NPP[3]. The system sensitivity was improved to 0.23m^3/h and both leak localization and leak size evaluation capabilities were incorporated. These target parameters were selected on the basis of the international standard IEC1250[4].

The experience accumulated on Leningrad NPP was integrated into the design of the present microphone system, which was installed on Fugen in April 1999. The main purpose of the development performed on Fugen is to design a method to detect a small leakage at an early stage and, thereby, method's concordance with Leak-Before-Break (LBB) detection should be studied as it is recommended in IEC1250.

The existence of the leak detection system with a detection capability of 1gpm (0.23m^3/h) within 1 hour is considered in the LBB concept while the maximum allowable leak rate is specified as 5gpm to take an appropriate margin, 5 times, against a piping break.

In the case of Fugen inlet piping, however, the piping diameter is smaller than the main coolant circuit pipes of an LWR and, therefore, it is more difficult to ensure the applicability of LBB concept

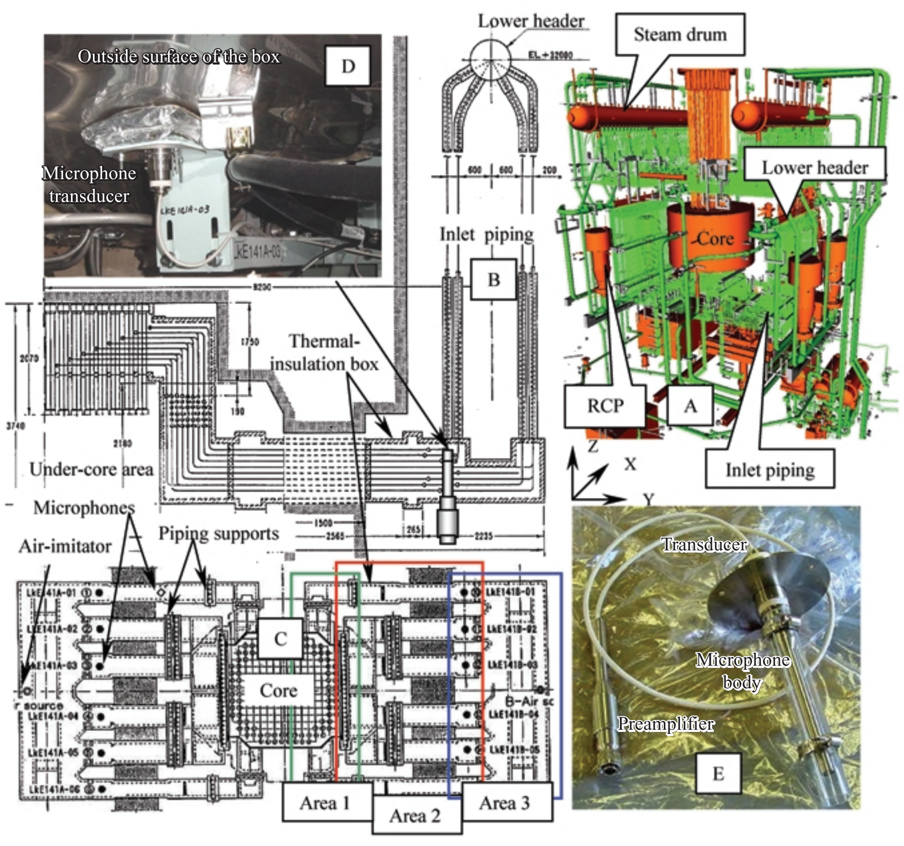

Fig.1 ATR Fugen: piping and microphone arrangement. (A) Main Systems of ATR Fugen, (B) Inlet piping of B-loop - cross-section X, (C) Thermal-insulation boxes and microphone arrangement - cross-section Z, (D) Microphone installation in the box, (E) High-temperature resistant microphone

because of lower rupture resistance of the piping and the requirement to detect smaller leakage. Specifically, the allowable leak rate for the inlet piping (⌀2 inch) was estimated as about 1gpm by pre-evaluation on LBB and, therefore, the smaller leak rate of 0.2gpm (0.046m^3/h) has been chosen as a target detection capability taking into account the safety margin, that is a factor of 5.

2. OBJECTIVE OF THE RESEARCH

The following main target requirements for the microphone leak detection system were formulated based on the previous conclusions:

- Ability to detect a leakage of 0.046m^3/h (0.2gpm) within 1 hour
- Estimation of the leak position with an accuracy of less than 1m
- Ability to evaluate the leak size

This paper presents results of the research carried out at Fugen in order to assess the ability of the method to satisfy these requirements, and to evaluate possible improvements, which could be achieved by more advanced leak detection techniques.

3. LEAK DETECTION SYSTEM

The microphone system installed on Fugen comprises 14 high-temperature resistant microphones as shown in Figure 1B,C. The microphones are of the condenser-type with a titanium membrane, crystal back-electrode and titanium casing that provides resistance to both temperature (up to 300°C) and radiation (up to 20R/h with 10^7R as a total integral dose). The microphone body is shown in Figure 1E.

Thermal-insulation boxes surround the inlet feeder pipes in order to minimize heat loss from the primary cooling system; hence, the microphone can be installed directly inside the box (Fig. 1B). In this case, the top of the microphone is inserted into the high-temperature environment and the transducer part is outside the box (Fig.1D).

Air leak imitators installed inside the boxes are used for sound generation by pressurized air discharge. This type of imitator is the safest method to simulate a leak sound inside the reactor building and the imitators can be used to check the system performance periodically during reactor operation and also to measure sound attenuation inside the boxes.

4. STANDARD APPROACH TO LEAK DETECTION

The standard approach is based on detecting acoustic signals emitted by leakage discharge by monitoring the increase in the sound pressure level (SPL) around piping.

The first step of the standard algorithm is the detection of an increase in SPL, where detection threshold and margin depend on the average level of BGN and its fluctuation. The second step is the leak localization procedure, which utilizes the analysis of SPL distribution between microphones in order to estimate leak position. The final step is an estimation of the leak size based on a correlation between the leakage flow rate and emitted sound power level (PWL) calculated for the assumed leak position.

In contrast with conventional leak detection methods (like monitoring of the amount of drain water in the sump and/or the radioactive level in a containment vessel), acoustic signals provide almost immediate reaction for leak appearance including information regarding a leak whereabouts. The standard amplitude-detection algorithm, in particular, has provided the leak detection within a few seconds that enables to shut a reactor down safely if a big leakage appears.

The present system, however, is intended to deal with small allowable leakages that makes it possible to extend the detection time up to 1 hour[4] and, through it, to use more sensitive statistical algorithms which usually take much more time for signal processing.

4.1 Comparative spectral analysis

A correlation between PWL, generated by coolant discharge, and the leak flow rate Q was formulated in JNC[5] via the empirical equations (1), based on the sound characteristics of coolant dis-

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charge, which were measured in a test rig.

$$PWL(f_i) = 10\log\left[\frac{C_i D^{a_i} F(P,T)}{10^{-12}}\right] \Leftrightarrow Q \approx 0.274\left(\pi\frac{D^2}{4}\right) \quad (1)$$

i – number of frequency band
C_i & a_i – empirical coefficients
D – equivalent diameter of leak hole
$F(P,T)$ – function of thermo-hydraulic parameters of coolant

Figure 2 shows that the PWL for the postulated leakage of 0.2gpm is relatively small compared with the leakages studied before over a wide range of frequencies. The shape of the PWL spectrum is changing as leakage is getting smaller with high-frequency region is getting more preferable for detection.

The attenuation equation (2) has been proposed to characterize sound attenuation as a function of distance from the sound source. In this equation the sound attenuation difference between emitted sound power level PWL and measured sound pressure level SPL is expressed as combination of expansion loss $10\log_{10}(1/4\pi r^2)$, friction loss $10\log_{10}\{\exp(-2\beta r)\}$ and transmission loss nL_s at the inlet feeder pipe supports (where r is distance, β is attenuation factor and n is number of piping supports).

$$PWL_m(f_i) = SPL_m(f_i) + nL_s - 10\log\left\{\frac{e^{-2\beta r_m}}{4\pi r_m^2}\right\} \pm 2\sigma \quad (2)$$

i – number of frequency band
m – number of microphone
r_m – distance between a sound source and m^{th} microphone

The tendency toward stronger sound attenuation at high frequencies was observed on both Leningrad NPP and Fugen, however, sound absorption by insulation material inside the boxes results in higher attenuation on Fugen (Fig.3).

Analysis shows that the re-circulation pumps (RCP) and the cooling fans are the main sources of BGN due to both the hydrodynamic noise, generated by coolant flow and the machinery noise, generated by RCP and fan motors, including the vibration of rotating parts.

BGN domination at low frequencies was observed on both Leningrad NPP and Fugen as shown in Figure 2. However, because external noise is attenuated by insulation material, the noise level on Fugen is much lower with a difference of about 20dB at the frequencies 10-20kHz.

Comparative analysis shows that due to the low level of emitted sound and significant attenuation, detection of the postulated leakage is possible only at high frequencies due to the low BGN level

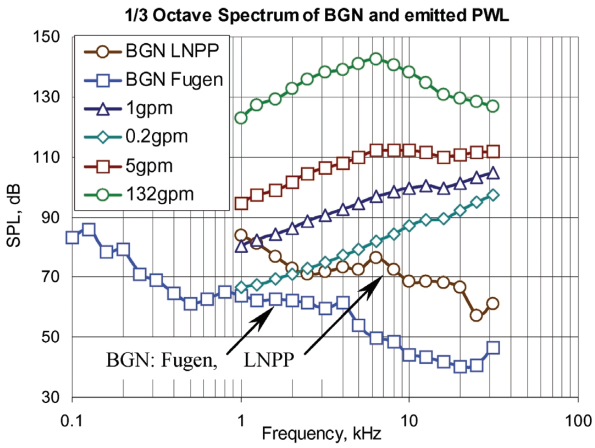

Fig.2 Emitted PWL and BGN spectra on nominal power

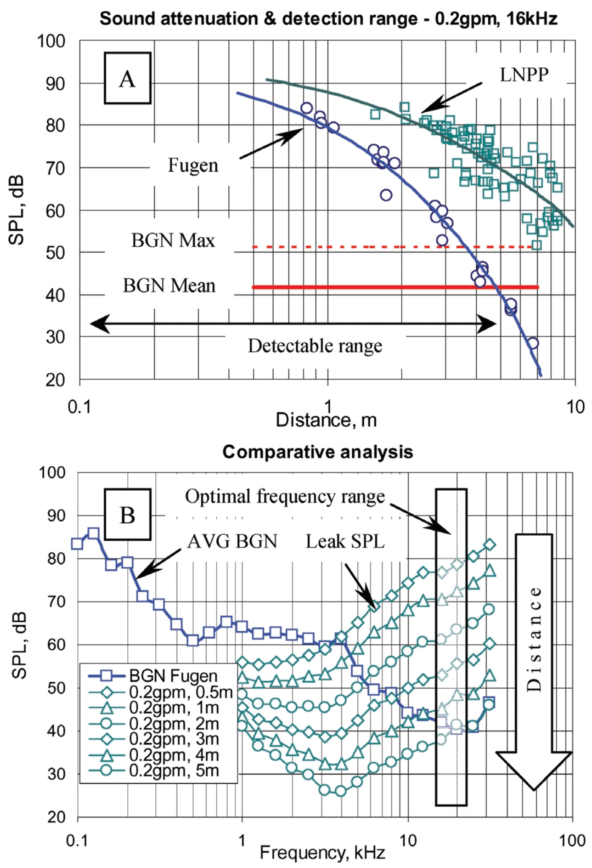

Fig.3. Sound attenuation analysis. (A) Detection range inside the boxes, (B) Optimal frequency range

there.

4.2 Evaluation of the system sensitivity

A detectable range can be described as a range of distances around the leak point where leak sound level is bigger than BGN and the leak signal can be easily detected.

The detectable range for the postulated leakage 0.2gpm was determined to be about 3.5-5m, Figure 3A; based on the averaged BGN level, the evaluated sound attenuation factor and the emitted PWL at the frequencies 16-20 kHz with highest signal/noise ratio (SNR) as shown in Figure 3B.

More detailed analysis has been performed with help of a 3D SNR diagram which is based on element-by-element comparison between BGN level and SPL of attenuated leak signal calculated by the equation (2) for every spatial element (a cube with size of 100×100×100mm) inside the monitored area with the given leak PWL and the attenuation constant β, already measured. The monitored areas are denoted as Area 1, 2 and 3 (Fig.1C) according to their different sound propagation conditions

This method is taking into account the spatial distribution of BGN, the relative location of microphones, their directivity and sound losses on the piping supports. Through it, the 3D SNR diagram can provide more accurate image of the detectable area under real geometry of the thermal-insulation boxes (Fig.4) that is also very useful for optimization of the sensor arrangement inside the boxes.

The SNR diagram (Fig.4) shows that leakage of 0.2gpm can be detected in Area 3; however, the detection of such leakage in Area 2 is possible for only about 50% of monitored area due to the sound losses on the piping supports and the significant attenuation.

To overcome this difficulty additional microphones could be installed in the boxes; however, installation of many additional microphones is not cost-effective and sometimes impossible due to limited access to the boxes and piping.

Thus implementation of more sensitive algorithms should be considered and examples of such methods are discussed in the paper.

4.3 Evaluation of the localization accuracy

The leak localization algorithm is based on analysis of relative attenuation of sound pressure between microphones inside a monitored area[6]. The monitored area is divided in a set of spatial elements where the current element is denoted as *ijk* according to its location in the XYZ axes. If leak location is assumed as the *ijk* position, SPL values measured by each microphone should correspond to the same value of emitted PWL, which

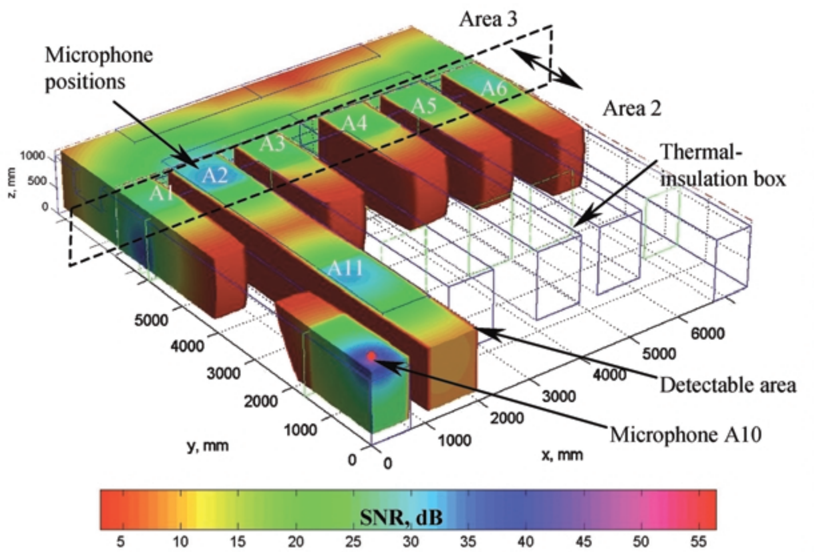

Fig.4 SNR distribution in Area 2 and Area 3 inside the boxes

can be evaluated by equation (2) based on the distance between m[th] microphone and this spatial position: $r_{m\to ijk}$ and the attenuation constant β, which is known in advance. Since it is unknown whether the current position ijk corresponds to the leak point or not, the expected PWL value is taken as the average PWL level calculated for all microphones according to the second line of equation (3). Then, the integral difference: δ_{ijk} between the expected PWL and the level actually measured by each microphone can be evaluated as it is defined in the first line of equation (3) where M is a total number of microphones under analysis. Obviously, the value of this difference is decreasing up to 0 as the current position: ijk is getting closer to the real leak point. Since it, the spatial point: ijk where the parameter δ_{ijk} becomes minimum can be assumed as a possible leak position.

$$\delta_{ijk} = \frac{1}{M}\sum_{m=1}^{M}\left|\left(SPL_{f,m} - 10\log\frac{e^{-2\beta r_{m\to ijk}}}{4\pi r_{m\to ijk}^{2}}\right) - \overline{PWL_{ijk}}\right| \tag{3}$$

$$\overline{PWL_{ijk}} = \frac{1}{M}\sum_{m=1}^{M}\left(SPL_{f,m} - 10\log\frac{e^{-2\beta r_{m\to ijk}}}{4\pi r_{m\to ijk}^{2}}\right)$$

The test results and results of numerical evaluations (Fig.5) show that the method has a spatial accuracy of about 300-600 mm for leakage of 0.2gpm under nominal reactor operating conditions, where the accuracy is affected by BGN fluctuations. The processing time was evaluated as 1-2min for Area 3 (6 microphones) and it is expected to be less than 10min for the entire monitored area.

Since the parameter δ_{ijk} is relatively small in the presence of a sound source (Fig.5A,B) and relatively large (Fig.5C) in the case of BGN (due to random distribution of SPL values between microphones), the combination of the parameters: δ_{ijk} & PWL evaluated for the assumed leak position has been used to verify the existence of the source and, thereby, to improve algorithm reliability.

5. IMPROVEMENT OF STANDARD APPROACH

Because the standard algorithm utilizes

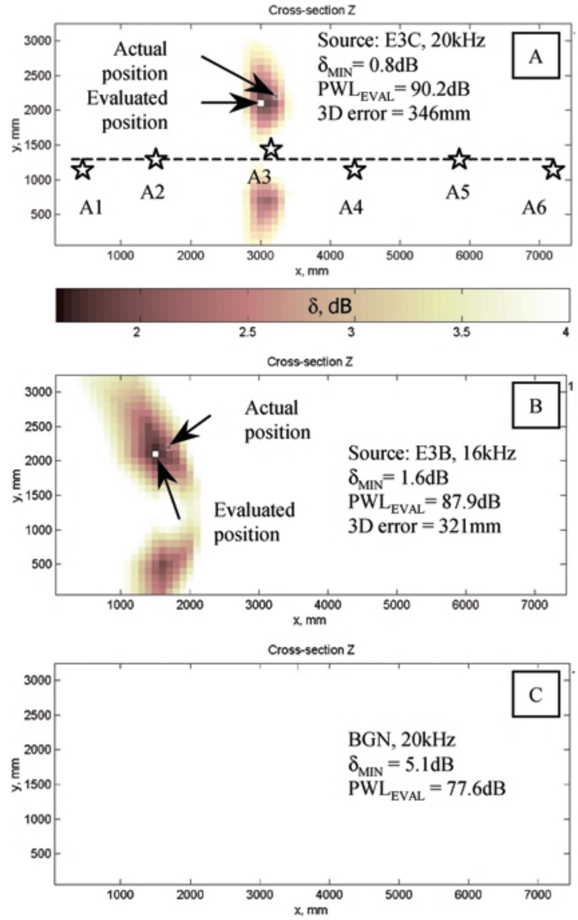

Fig.5 Leak localization (cross-section Z) based on SPL analysis for different source locations: (A) E3C, (B) E3B and (C) in the case of BGN

amplitude-based detection, improvement of detection sensitivity is possible only by lowering detection margin and using a floating detection threshold.

Since low detection margin can result in detector malfunction, methods to suppress BGN fluctuations and to improve algorithm robustness are also necessary.

5.1 Probabilistic detection criterion

A probabilistic detection criterion with relative detection threshold was proposed as suitable statistical algorithm which is able to minimize the probability of a false detection while an averaging processing can be used to suppress BGN fluctuations.

This criterion is based on comparison between the statistical hypothesis which supposes that the signal level has changed at some moment within observed time interval, and the contrary hypothesis which supposes that such change did not occur.

Applying the technique for root-mean-square (RMS) values of acoustic signals shows that averaging processing makes it possible to keep BGN fluctuations within 0.5dB under nominal power operation; thus, minimum detectable level (MDL) in the criterion can be lowered by up to 0.5dB. The instant when the change occurs can also be determined (Fig.6A); however, lowering minimum detectable level to below 0.5dB can result in a decrease in the detection accuracy (Fig.6B).

Hence, combination of the criterion with the averaging technique helps to avoid detector malfunction caused by short-term BGN fluctuations while the possibility of updating the floating detection level periodically makes the algorithm more robust in the case of long-term fluctuations.

The processing time has been evaluated as 0.5-1 min per channel for signals of 30 min length under off-line processing. However, since the proposed length of processing data block is 5 min and the algorithm is suitable for a parallel on-line processing, the overall detection time can be kept within 5 min.

6. FURTHER ANALYSIS

The detectable range provided by the standard approach is quite low principally due to sound propagation conditions inside the boxes. Indeed, the sound attenuation is so high (about 10dB/m for $\beta \approx 1$) that signals almost disappear at a distance of 9m from the postulated leakage (with PWL≈90dB). In practice, the range is limited to 6-7m due to the presence of internal electric noise in the measurement channel (the equivalent level is about $25dB_{SPL}$).

Further limitations of the detectable range (3-5m) are caused by the presence of BGN and applicability condition of the amplitude-based detection, that is SNR>0dB. By contrast, applicability of the correlation-based detection is possible even if SNR<0dB.

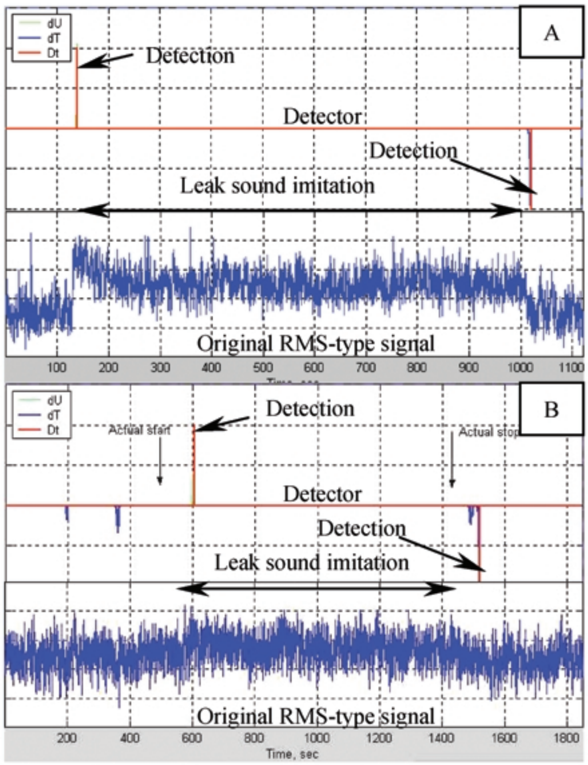

Fig.6 Probabilistic detection test, △F=4-30kHz: (A) MDL=1dB, D=3.5m; (B) MDL=0.4dB, D=4.6m

A Cross-Correlation Function (CCF) can be treated as two-channel algorithm, which provides a measure of linear relation between two time signals. In an ideal situation, the signals emitted by sound source can be treated as the same signal, which is amplitude-scaled and time-shifted in different manner due to difference in propagation paths. Through it, the location of CCF peak on a time axis corresponds to the time delay between arrivals of two signals (Fig. 7A) while the presence of the peak is a clear sign that a coherent source is present nearby.

Due to its nature, CCF will be not seriously affected by linear independent noise even if its amplitude is much bigger than amplitude of signals provided by ideal sound source. Thereby, based on a model of coherent point-type source and non-correlated diffusion-type BGN, CCF could be employed in order:

- to detect the presence of a coherent source in BGN
- to determine the source location via analysis of Time-Differences-Of-Arrival (TDOA) of sig-

nals

However, a linear-relation between signals and, as result, a correlation will quickly degrade if signals are distorted under propagation due to a multiple reflection and diffusion on obstacles. In particular, performance of the correlation-based algorithm can be affected by the complicated geometry inside the boxes and the diffusion of sound on the pipes. Figure 7 shows examples of CCF measured in free space (Fig.7A) and inside the boxes under reactor shutdown conditions (Fig.7B). It is clear that even in the absence of BGN the magnitude of the cross-correlation peak is much lower and, because its shape is significantly spread, the peak's position cannot be determined clearly. The situation worsens if leak signals are placed into BGN as shown in Figure 7C.

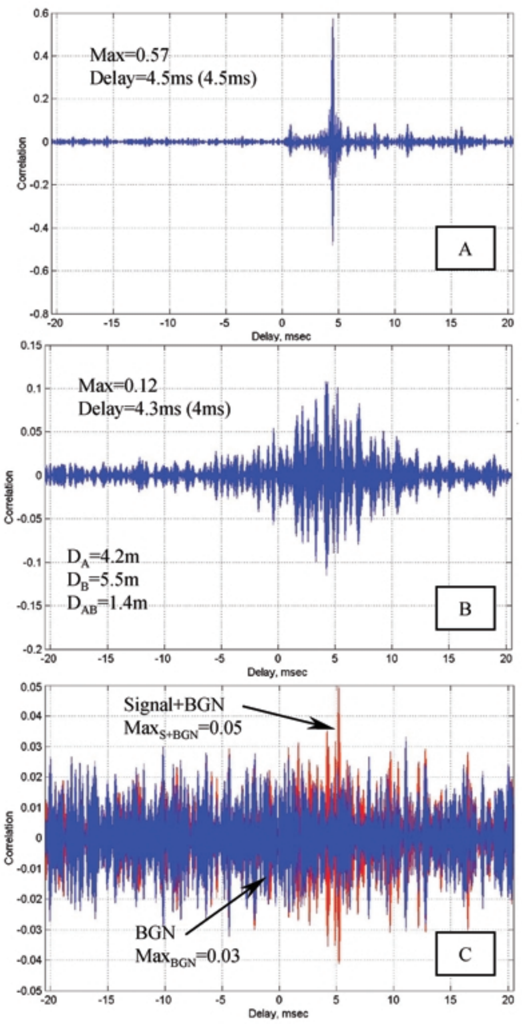

Fig.7 Cross-correlation function: (A) Leak sound in free space, (B) Inside the thermal insulation box, (C) In presence of BGN

The factors that can affect correlation between signals inside the boxes and applicability of the correlation-based detection algorithms there should be evaluated.

6.1 Cross-correlation characteristics

Particular attention has been paid to studying the dependence of the correlation factor on (1) relative location of source & sensors and (2) SNR in both correlated channels.

Figure 8 shows the decline of cross-correlation factor as a distance between source and microphone is increased while maximum correlation values were measured between closest microphones.

The SNR affects the correlation level in accordance with equation (4), which can be derived from a standard definition of the cross-correlation factor supposing that BGN has some finite correlation level: ρ_{NaNb}. A good compliance has been observed between the equation and actually measured values of cross-correlation factor inside the boxes.

$$\rho_{AB}(\tau) = \frac{\rho_{SaSb}(\tau)\sqrt{SNR_A SNR_B} + C_0\,\rho_{NaNb}(\tau)}{\sqrt{SNR_A SNR_B + SNR_A + SNR_B + 1}} \qquad (4)$$

ρ_{SaSb} – correlation level in absence of BGN
ρ_{NaNb} – BGN correlation level
$SNR_{A/B}$ – signal/noise ratio in channel A/B

Analysis of these factors shows that leakage of 0.2gpm can be detected by increase of cross-correlation value under average levels of BGN. However, due to low correlation, the detection sensitivity degrades significantly under maximum BGN levels observed inside the boxes, and detection is possible only in particular areas, where SNR ≥ -3dB (Fig.9), taking into account the background correlation level, that is about 0.03～0.05.

This outcome leads to the conclusion that the coherent point-type source model is not completely appropriate for the limited space inside the boxes where the sound source has a finite physical size and sound diffusion on the piping is relatively strong.

Under such circumstances the source might be

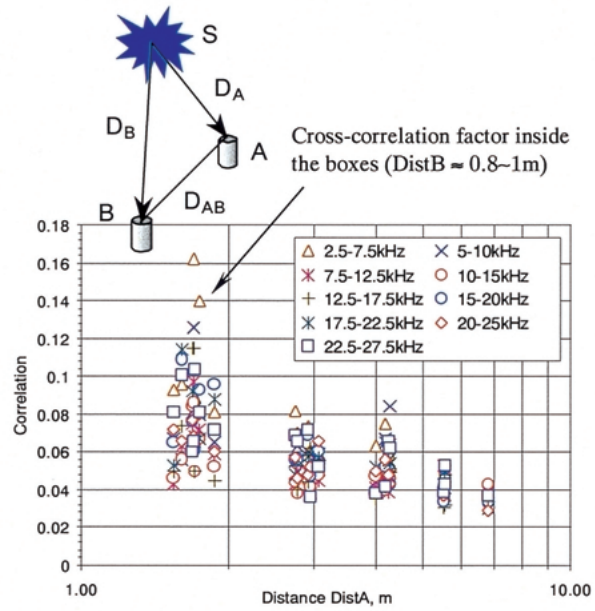

Fig.8 Cross-correlation and relative location of source and sensors inside the boxes

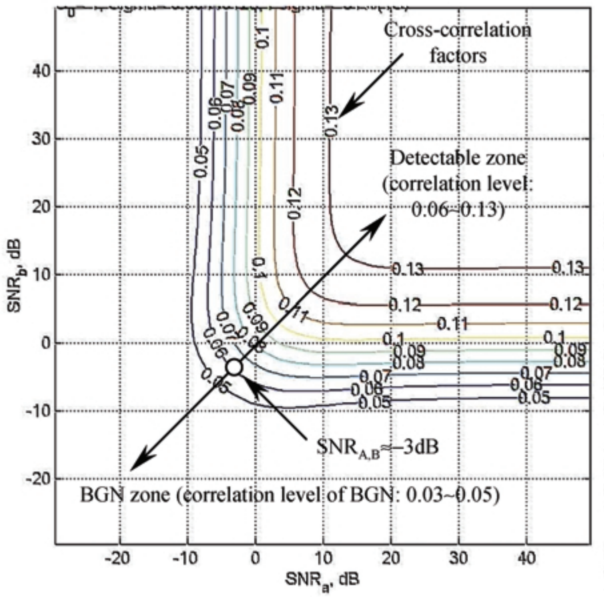

Fig.9 Dependence of cross-correlation factor on SNR of channel A and B inside the boxes (△F=17.5～22.5kHz)

described as spatially distributed and can be treated as a number of simultaneous non-correlated sources resulting in low-correlation between signals.

6.2 Basis for improvements

The previous analysis shows that correlation does not provide significant detection advantages inside the boxes if it is used directly. Nevertheless, the correlation-based approach has room for improvement.

In particular, spatial-compactness of the sound source and spatial distribution of BGN can provide the basis for location-based detection and the related algorithms. Also a multi-channel approach makes it possible to improve sensitivity via superposition of many detection parameters related to different microphone pairs.

Based on these ideas, the following algorithms and parameters were proposed:

- Location-based detection algorithm, which employs a spatial selectivity based on leak localization procedure
- Multi-channel processing associated with estimated leak position

6.3 Location-based detection algorithm

This method utilizes a localization procedure based on analysis of TDOA data derived from CCFs.

Source location can be estimated as the point: *ijk* in 3D space, which minimizes an error criterion: ψ_{ijk}, defined by equation (5) that is a function of the TDOA data: τ_n (where n is number of microphone pair) and a hypothesized leak location. In this equation τ_n is derived directly from CCF of two signals for n^th^ microphone pair while τ is theoretically expected TDOA value, which is determined by the coordinates of given spatial point p_{ijk} and the coordinates of two microphones (A and B) of n^{th} microphone pair - m^{AB}_n.

$$\psi_{ijk} \approx \frac{1}{N}\sum_{n=1}^{N}\left|\tau_n - \tau(m_n^{AB}, p_{ijk})\right| \Rightarrow \Psi \approx \frac{\psi_{thr} - \psi_{ijk}^{\min}}{\psi_{thr}} \quad (5)$$

$p_{ijk}=[x_i\, y_j\, z_k]$ – coordinates of current spatial point denoted as *ijk*
$m^{AB}_n=[x_A\, y_A\, z_A;\, x_B\, y_B\, z_B]$ – coordinates of n^{th} microphone pair (microphones *A* and *B*)
N – total number of microphone pair

This method is theoretically more accurate than the SPL-based method; however, signal distortion results in TDOA fluctuations and so accuracy decreases up to 500-900 mm.

Nevertheless, in the presence of a leak TDOA data will correspond to a spatial point, which is close to actual leak location; therefore, the value of the error criterion should be small. Since BGN is diffusion-type noise, CCFs related to BGN have randomly distributed peaks, hence, the error value Ψ_{ijk} should be larger.

The location-based detection algorithm employs this difference via localization factor: Ψ chosen as the detection parameter. Ψ is proportional to $(\Psi_{thr} - \Psi_{ijk})/\Psi_{thr}$, where Ψ_{thr} can be taken as maximum Ψ_{ijk} value observed and, through it, Ψ value can be kept within [0-1] range. The processing time of has been evaluated as about 3 min in Area 3 (6 microphones, 15 microphone pairs).

Figure 10 shows that the presence of leakage could be easily detected by the localization factor, which was evaluated as about 0.9 in the presence of the source (Fig.10A) and less then 0.3 for BGN (Fig.10B). The reliability of this algorithm is also higher because it utilizes data from many (N) microphone pairs located inside the boxes.

6.4 Multi-channel approach

Detection efficiency can be also improved by employing a multi-channel technique, which is proposed as superposition of time-delay compensated CCFs related to different pairs of microphones.

Since cross-correlation provides two-channel algorithm, it can be formally generalized to multichannel version by increasing the number of channels. Such multi-channel function contains all pairwise combination of the delay-compensated two-channel functions calculated for every possible delay. This algorithm, however, is non-efficient for practical applications due to its vulnerability to time-delay fluctuations caused by signal distortion and because it takes a huge amount of calculations.

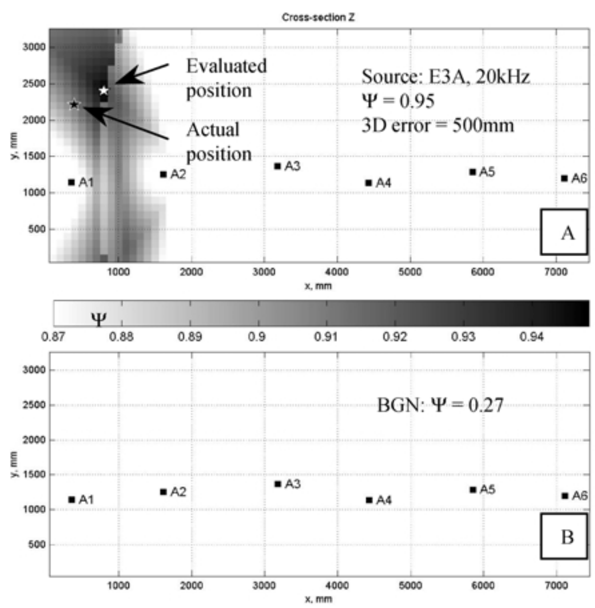

Fig.10 Leak-based detection via CCF analysis: (A) In presence of leak source, (B) BGN

In the proposed method, however, calculation of all possible delays is avoided since the supposed leak point could be approximately evaluated via TDOA analysis and delay compensation could be performed only within the range of time-delay values corresponding to spatial area around this point.

In the presence of a leak source, time-delay compensated CCFs are focused at the region around the source with their peaks close to the zero-delay (Fig.11A), while the functions related to BGN have randomly distributed peaks. The multi-channel-type CCF shown on Figure 11B can be prepared via superposition of these functions to amplify peaks that are source-related and suppress those that are BGN-related.

The technique makes possible detection of signals with SNR<-3B at distances up to 5.5m; furthermore, the detection efficiency increases as the number of processed channels is increased (Fig.11C). The processing time has been evaluated within 2-4min that depends on a number of channels.

This multi-channel-type CCF associated with estimated source-location can be easily integrated into the location-based detection algorithm providing an additional detection parameter in order to improve detection reliability.

CONCLUSION

The possibility of detecting and locating a small leakage in accordance with the requirements applied for the inlet piping has been demonstrated through this research. The probabilistic detection criterion and a combination of multi-channel- and location-based detection algorithms are proposed

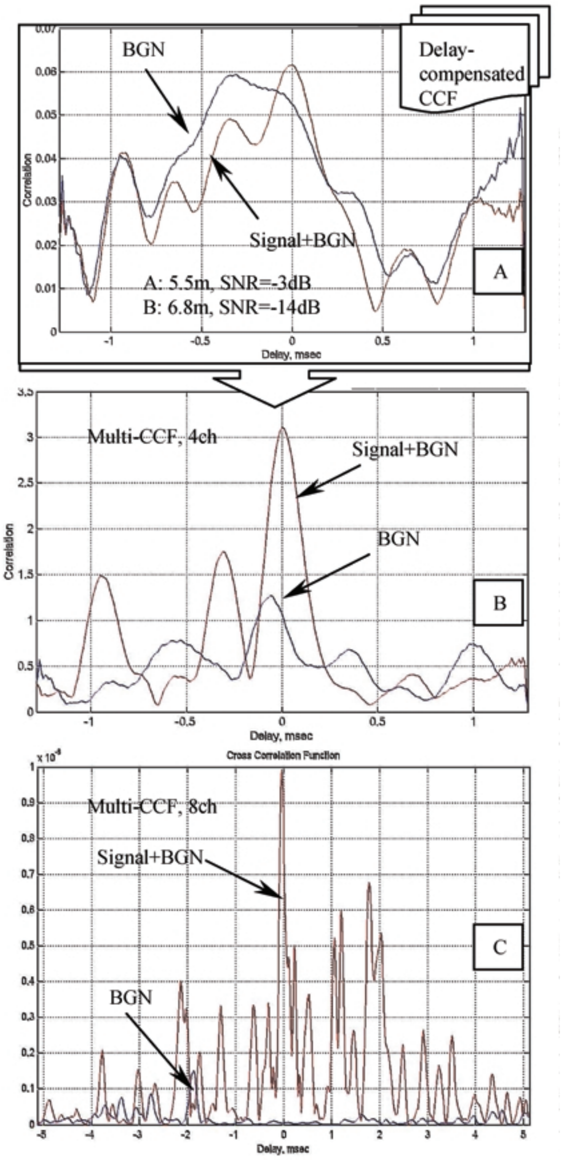

Fig.11 Multi-channel processing of CCF (Hilbert transform): (A) Delay-compensated CCF, (B) Multi-channel-type CCF-4ch,(C)Multi-channel-type CCF -8ch

in order to improve both the detection sensitivity and reliability.

The present research is based on analysis of artificial leak signals, simulated by the air imitator. These signals are assumed to be of the stationary-noise type which would not be entirely true for real leakage.

The tests carried out in RDIPE[1] showed that local pulsations of coolant pressure could cause burst-type acoustic noise emitted by leak flow through a real crack.

In the next stage of the research it is proposed to focus on verification of the algorithms for real leak signals and on analysis of its non-stationary components - supposed to be less affected by distortion - which can be extracted from BGN by Wavelet decomposition.

ACKNOWLEDGMENTS

The present results were obtained in the framework of JNC Fellowship Program funded by the Government of Japan.

The authors would like to express their sincere gratitude to Mr. S.Sawai (Pesco) and many other specialists from JNC, Hitachi Ltd, Pesco Co. Ltd etc, who have assisted this research.

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