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A New Discrimination Technique between the Impact Signal by Metallic Object and the Thermal Shock Signal using the Ambiguity Function

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1. Introduction

In order to detect and monitor metallic objects in the primary system of operating nuclear power plants, the Loose Part Monitoring System (LPMS) is in operation.

This system (LPMS) detects the existence of metallic objects that are separated from the internal structure of the reactor due to mechanical damage, corrosion, fatigue, etc., and metallic objects introduced from outside the system during maintenance, and provides data for experts to analyze the risk of metallic objects [1].

In an operating nuclear power plant, thermal expansion of a structure occurs according to an operation mode, and as a result, a thermal shock signal similar to a metal foreign body shock signal is generated.

The alarm caused by the thermal shock signal is also called a false alarm, and since it is a phenomenon caused by the operational transient, it should be distinguished from the alarm caused by metallic objects (True Alarm).

However, most of analysis algorithms applied to the equipment in operation at nuclear power plants identify the thermal shock signal as the metallic objects shock signal and generates excessive false alarms [2, 3].

To solve this problem, a new technique for discriminating a thermal shock signal is required.

In this paper, we intend to compare and analyze steel ball impact signals and thermal shock signals by applying the time-frequency analysis technique and the ambiguity function, and present a new analysis technique for discrimination. In addition, the presented analysis technique is intended to be used in future research for the development of the monitoring system using artificial intelligence algorithms.

2. Methods and Results

2.1 Theory of Time-Frequency and Ambiguity Function

When an impact is generated by a metallic object in the plate or shell structure, the shock wave propagates from the impact location.

As a signal processing technique that analyzes these dispersion characteristics, there are various time-frequency analysis techniques. Time-frequency techniques include Short Time Fourier Transform, Wavelet Transform, and Wigner-Ville Distribution.

Among them, Wigner-Ville Distribution (WVD) is a Fourier transformation of a time-dependent autocorrelation function with respect to time delay. On the other hand, a Fourier transformation of the autocorrelation function with respect to absolute time can be performed, which is called an ambiguity function [4, 5].

$$W(t,f)=\int_{-\infty}^{\infty} x\left(t-\frac{\tau}{2}\right)x^{*}\left(t+\frac{\tau}{2}\right)e^{-j2\pi f\tau}d\tau$$

$$A(\xi,\tau)=\int_{-\infty}^{\infty} s\left(t-\frac{\tau}{2}\right)s^{*}\left(t+\frac{\tau}{2}\right)e^{-j2\pi\xi t}dt$$

Fig. 1 is an example of analyzing an impact signal using Wigner-Ville Distribution and Ambiguity Function.

It can be seen that the Wigner-Ville Distribution shows the dispersion characteristics of the shock wave well, and the result of applying the ambiguity function is widely distributed along the ξ axis (related to frequency), indicating that both techniques exhibit dispersion characteristics.

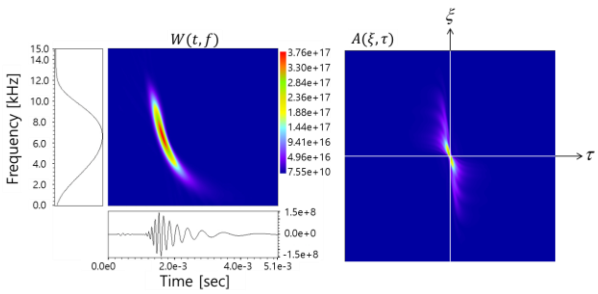

Fig. 1. Results of applying the time-frequency analysis technique and the ambiguity function to an impact signal.

2.2 Characteristic of steel ball impact signals

In order to investigate the propagation characteristics of the shock wave when the impact is caused by a metallic object, steel balls of various masses(56gram, 220gram, 450gram) were used to impact the lower part of the steam generator at a nuclear power plant and the signals were collected.

Time-frequency analysis and ambiguity function were applied to the collected shock signals to analyze their characteristics.

Fig. 2 shows the analysis results, it can be seen that in the case of the time-frequency analysis technique, the larger the mass of the steel ball, the better the dispersion characteristics are, but the smaller the mass, the less well the dispersion characteristics appear.

It can be seen that the analysis results applying the ambiguity function show the dispersion characteristics well in the ξ axis (related to frequency) regardless of the weight.

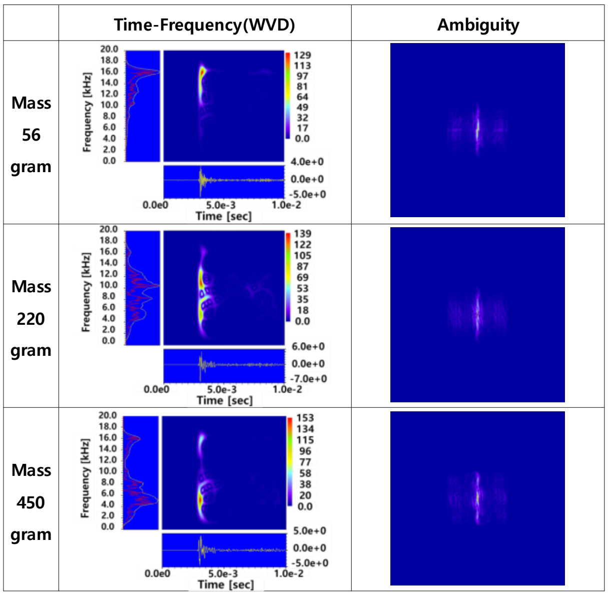

Fig. 2. Results of time-frequency analysis of steel ball impact signal and result of applying ambiguity function.

2.3 Comparative analysis of thermal shock signals

Thermal shock signal data generated during operation of the nuclear power plant were acquired and the characteristics of the thermal shock signal were analyzed.

As a result of analyzing the thermal shock signal, it was found that it had different characteristics from the steel ball impact signal.

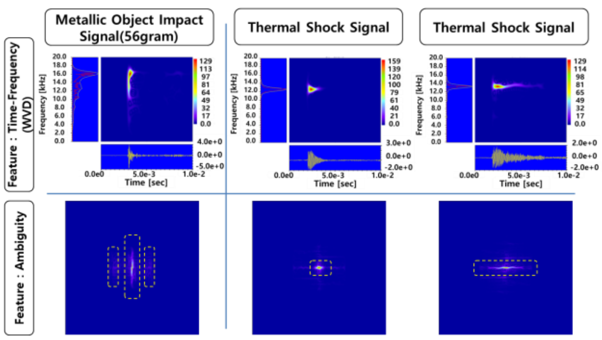

Fig. 3. Comparison of time-frequency analysis results and results of applying the ambiguity function for steel ball impact signals and thermal shock signals.

As shown in Fig. 3, it can be seen that the thermal shock signal exhibits a characteristic of gradually attenuating around the resonance frequency band of the acceleration sensor.

In the Wigner-Ville Distribution analysis result, it can be seen that the characteristics are similar when compared with the steel ball impact signal having a small mass, but the characteristics are different from the result of applying the ambiguity function.

Therefore, as a technique capable of discriminating between a metallic object impact signal and a thermal shock signal, a technique applying an ambiguity function is proposed.

3. Conclusion

A feature extraction technique for determining the authenticity of metallic object impact signals and thermal shock signals was proposed.

The characteristic of the metallic object impact signals are a dispersion characteristic accompanying a wide band of frequency, and the characteristic of the thermal shock signals are a characteristic of gradually attenuating around a mounted resonance frequency.

In this paper, signal processing was performed using ambiguity function to distinguish between metallic object impact signals and thermal shock signals, and the proposed technique was verified by comparing and analyzing the results.

In the future, the features extracted through the proposed signal processing method will be used for discrimination technology using an artificial intelligence model.

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