한국소음진동공학회 2004년도 추계학술대회논문집, pp. 311~316.

Application of a Continuous Wavelet Transform to the Impact Location Estimation in Plate Type Structures

Jin-Ho Park*, Jeong-Han Lee*, Gee-Yong park*

Key Words: Group delay, Impact location estimation, Time-frequency analysis, Continuous Wavelet Transform, Loose Parts Monitoring System

ABSTRACT

For the location estimation in the conventional LPMS(Loose Parts Monitoring System), it is popular to employ a group delay among the acoustic sensors installed within a 3 ft range from the impact source. However, there exists inherent error in determining the arrival time differences of the generated wave group among the neighboring sensors. To overcome this problem in this study, the two dimensional approach has been proposed and applied to effectively estimate the arrival time differences by using a continuous wavelet transform which is one of the linear time-frequency analysis methods. The experiment has been performed to both the plate model and the real steam generator in a nuclear power plant. It is expected that the reliability of the location estimation could be enhanced when the proposed time-frequency method is introduced into the LPMS system.

1. INTRODUCTION

LPMS(Loose Part Monitoring System) is one of the NSSS(Nuclear Steam Supply System) structural integrity monitoring systems and should give as useful information to identify the location of the loosened or detached metals which are called loose parts. There have been many papers and reports issued for the estimation of the impact position of the loose parts[1][2][3][4]. The main concept of the impact location estimation is based on the arrival time difference of the impact stress wave between the different sensor locations Then if the speed of the acoustic wave is known and two or three sensors are properly positioned nearby, we can easily localize the impact source. But this is not always the case in the actual power plant since the number of sensors are limited and also there exists various kinds of noise sources depending on the operating status of the plant.

Conventionally, the one dimensional stationary signal analysis has been

*Korea Atomic Energy Research Institute, 150 Duckjin-dong, Yusung-Gu, Daejeon City, Korea
E-mail: pjh213@kaeri.re.kr

widely applied to determine the time differences between the neighboring sensors in analyzing the impact source location and the spectral characteristics of the transient signals due to the impact[1][2]. Recently, the two dimensional time-frequency analysis technique has been introduced and the possibility for its application to LPM technology has been addressed[3][4][5]. The loose part signals are inherently non-stationary and dispersive, thus the two dimensional analysis is expected to provide more useful information for analyzing the impulse response characteristics of the loose part signals.

The CWT(Continuous Wavelet Transform) which is one of the time-frequency analysis techniques is introduced and applied to the location estimation of the impact source in the case of a plate and a steam generator of a real power plant.

CWT(CONTINUOUS WAVELET TRANSFORM)

CWT(Continuous Wavelet Transform) is one of the time-frequency analysis techniques such as STFT(Short Time Fourier Transform), Wigner-Ville distribution, etc[6][7]. It is being popularized in many kinds of engineering fields since it is a linear transform analogous to STFT and has more useful characteristics than STFT. The CWT is defined as

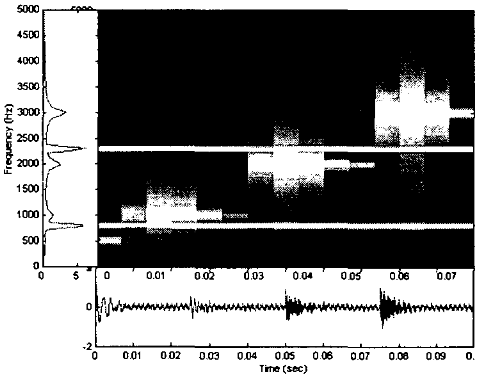
$$CWT(a,b) = \int_{-\infty}^{\infty} s(t)\psi^{*}\left(\frac{t-b}{a}\right)dt \quad (1)$$

$$= \int_{-\infty}^{\infty} s(t)e^{-\left(\frac{t-b}{a}\right)^2/\sigma^2} e^{j2\pi\frac{f_0}{a}(t-b)}dt$$

Where the function Ψ(t) is called the mother wavelet which is expressed by

$$\psi(t) = Ae^{-\left(\frac{t-b}{a}\right)^2/\sigma^2} e^{j2\pi\frac{f_0}{a}(t-b)} \quad (2)$$

This mother wavelet is scaled by 'a' in the frequency domain and shifted by 'b' in the time domain. The window size of the CWT is controlled by a scaling factor 'a'. The main difference



APPLICATION OF THE CWT TO THE IMPACT LOCATION ESTIMATION

It has already been proved that the time when the peak of the magnitude of the CWT indicates the arrival time of the dispersive bending wave corresponds to the frequency at the peak point with the group velocity in case of a plate[8]. Therefore, it is expected that the arrival time of the dispersive wave will be more easily identified through the two dimensional time-frequency plane obtained from the CWT analysis than the conventional time domain analysis.

To investigate the validity of the CWT technique for the location estimation of the impact source, an experiment has been performed with two different types of structures; One is the plate model, and the other is a lower part of a real steam generator which has a form of a cylindrical shell. Figure 3 shows the locations of the impact points and the acceleration sensors of the plate model. The impact is generated by dropping a small steel(around 10 g) ball from 10 cm above the plate surface. The analyzed time-frequency distributions of the measured acceleration signals using the CWT are illustrated in Figure 4. The dotted red color lines, which are PML(peak magnitude lines), show the arrival time point corresponding to each frequency component of the propagating wave group. Based on the PMLs, the relative time differences between the three sensors and the group velocities to the corresponding frequencies are calculated, and also the impact locations are estimated and compared to the true impact point as shown in Figure 5. The results show a good agreement with each other.

Similar test has also been implemented on the lower part of a steam generator in a real power plant. The impact and the sensor locations are described in Figure 6. The impact force is excited by hitting a 100 g steel ball on to outer surface of the structure 40 cm apart from the sensor ACC-S0. It has been assumed that the cylindrical and the spherical shell parts are developed as a plate and the sensors are located on the same surface. The time-frequency distributions obtained from the CWT analysis are depicted in Figure 7 and the peak magnitude lines in Figure 8. The impact locations are calculated by using the group delays at two different frequency points on the peak magnitude line of the time-frequency plane. Both are in excellent agreement with the true impact point shown in Figure 9.

In summary, it is revealed that the CWT technique provides a useful means for the impact location estimation of the plate and cylindrical shell structures. Therefore, it is expected that the reliability of the location estimation could be enhanced when the proposed time-frequency method is introduced into the LPMS system.

CONCLUSIONS

It has been found that the CWT technique is applicable to reliably detect the impact signal and estimate the impact source location generated on the surface of a plate type structure and also to enhance the source location ability in the conventional LPM system.

ACKNOWLEDGEMENT

The support of Korea Ministry of Science and Technology is appreciated.

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Fig. 3 Schematic of the Plate Model
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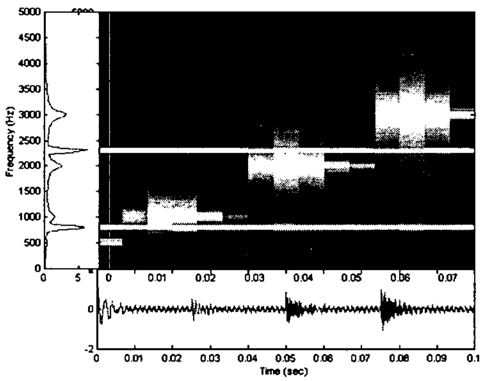

Fig. 1 Example of STFT

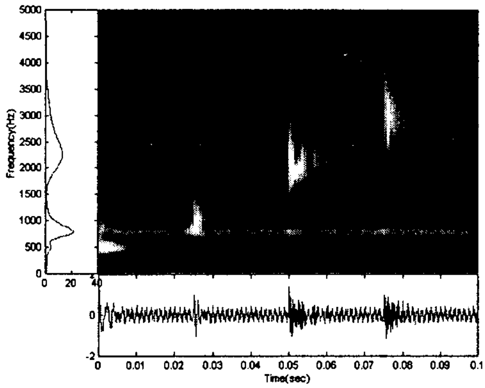

Fig. 2 Example of CWT

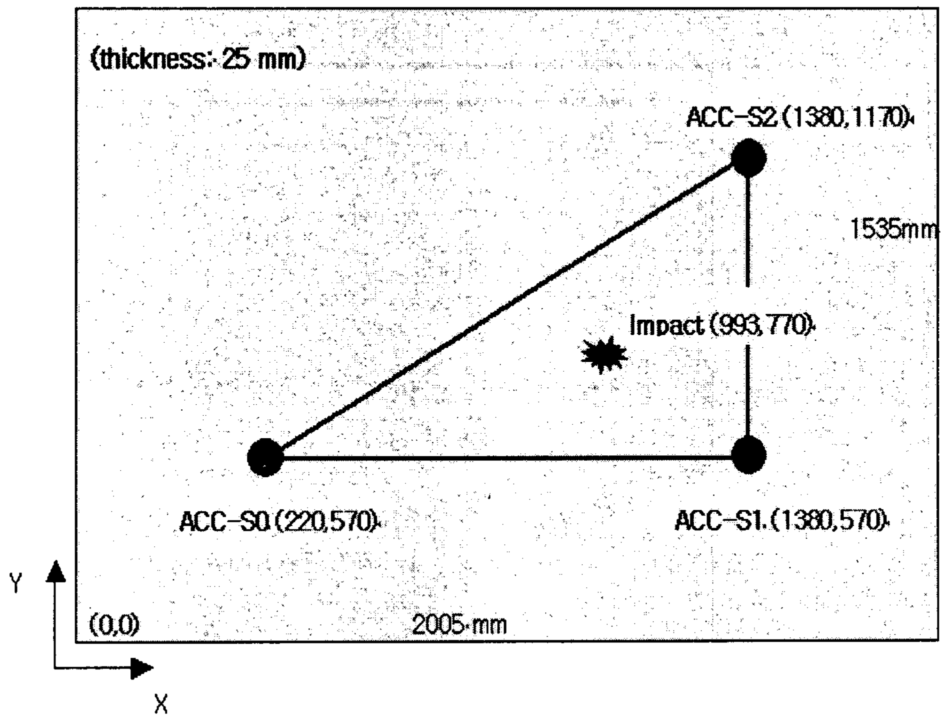

Fig. 3 Schematic of the Plate Model

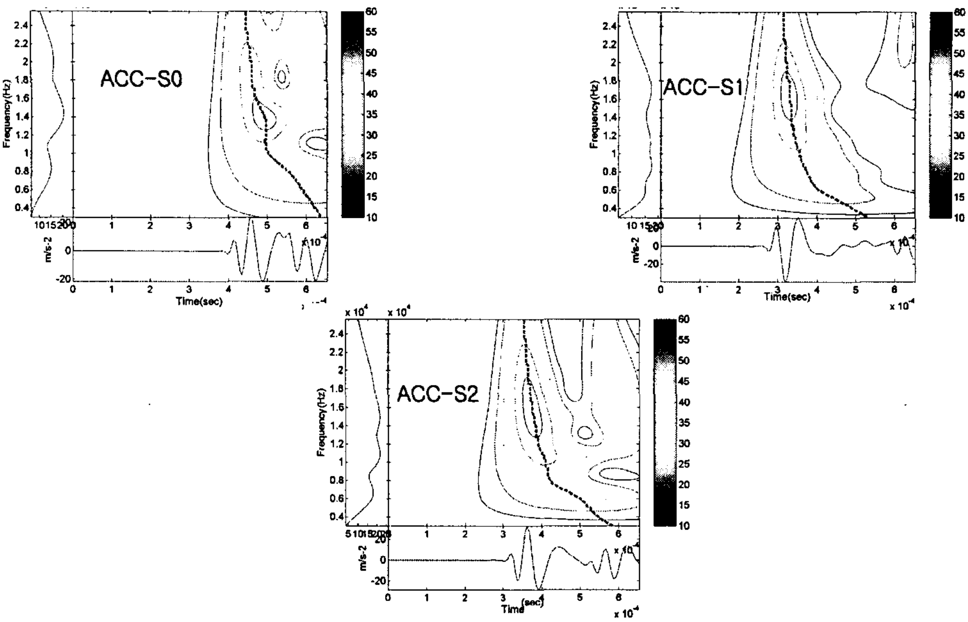

Fig. 4 CWT Analysis of the Measured Response Signals(Plate)

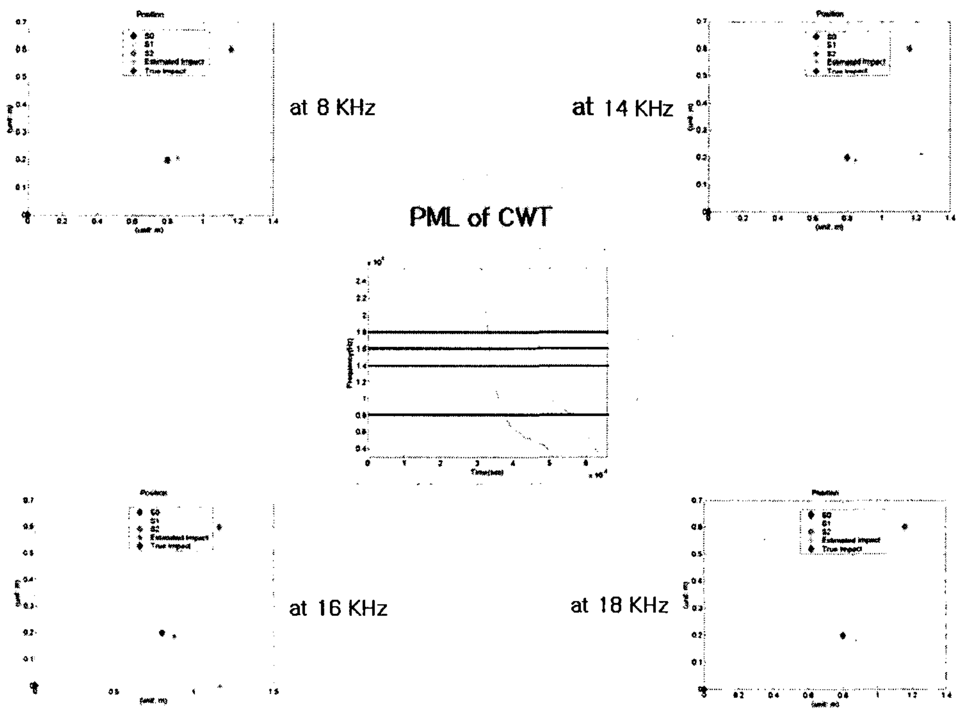

Fig. 5 Location estimation by Peak Magnitude Lines of CWT(Plate)

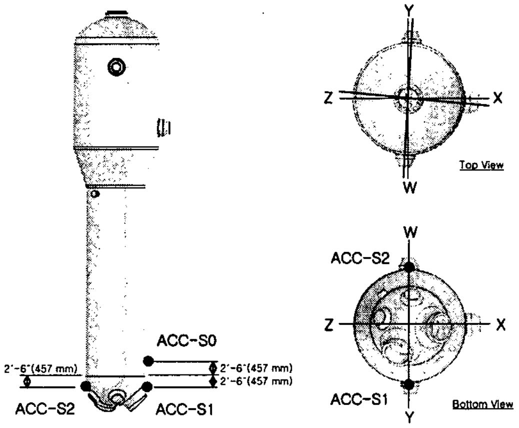

Fig. 6 Sensor Location of the Steam Generator

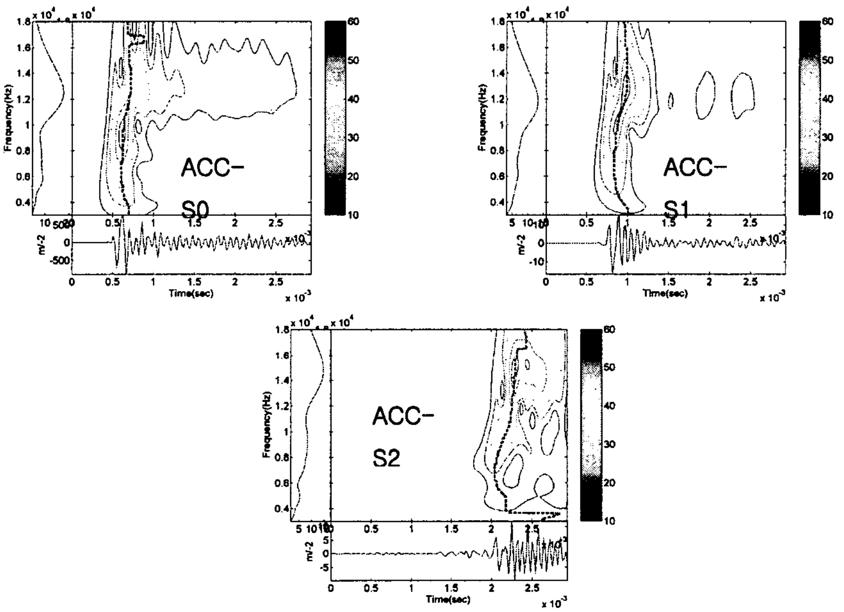

Fig. 7 CWT Analysis of the Measured Response Signals(Steam generator)

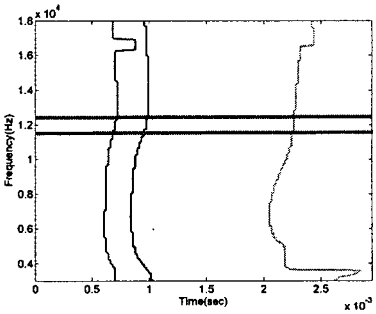

Fig. 8 Peak Magnitude Lines of CWT(Steam Generator)

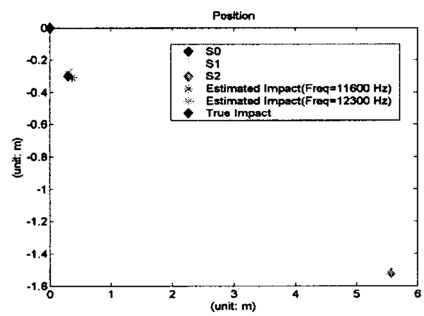

Fig. 9 Location Estimation of the Impact for the Steam Generator