한국소음진동공학회 2005년도 추계학술대회논문집, pp. 107~111.

시간 주파수 분석을 이용한 충격발생 위치 추정
Source Localization of an Impact on a Plate using Time-Frequency Analysis

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Key Words : Time-Frequency analysis, STFT, WVD, CWT.

ABSTRACT

It has been reviewed whether it would be suitable that the application of the time-frequency signal analysis techniques to estimate the location of the impact source in plate structure. The STFT(Short Time Fourier Transform), WVD(Wigner-Ville distribution) and CWT(Continuous Wavelet Transform) methods are introduced and the advantages and disadvantages of those methods are described by using a simulated signal component. The essential of the above proposed techniques is to separate the traveling waves in both time and frequency domains using the dispersion characteristics of the structural waves. These time-frequency methods are expected to be more useful than the conventional time domain analyes for the impact localization problem on a plate type structure. Also it has been concluded that the smoothed WVD can give more reliable means than the other methodologies for the location estimation in a noisy environment.

1. Introduction

The impact source localization technique on a plate type structure using acceleration response signals has been widely applied to the detection of loose parts in nuclear power plants[1][2][3].

Conventionally, the localization is achieved only in the time domain which means that one dimensional signal analyses have been performed to determine the TOAD(time-of-arrival difference)s between the neighboring sensors. Recently, the two dimensional time-frequency analysis techniques have been introduced and the possibility for application to the LPM technology has been addressed[4][5][6][7]. The loose part signals are inherently non-stationary and dispersive, that is, the higher frequency components in the signal propagate faster than the lower frequency ones. Thus the two dimensional analysis is expected to provide more useful information on the transient behaviours of the impact response signals.

The time-frequency analysis techniques being currently utilized in various engineering fields are introduced and the characteristics of those methods compared one another to apply for the location estimation of the impact source on a plate type structure. The experiment is also being conducted to verify the usefulness of the time-frequency analysis for the localization of the impact source.

2. Time-frequency Analysis

The Fourier transform technique has widely being used to analyze the dynamic characteristics of the linear time invariant system in the area of structural integrity monitoring and diagnoses. It is well known that the Fourier transform gives global information of the signal by the definition that it has a whole waveform function as a basis. This means a small amount of local frequency perturbation at a particular time could not identified in this analysis. This is because we are going to introduce the new techniques called as the time-frequency analysis. The time-frequency analysis is a local analysis, by which we can extract the local(transient) frequency components in a signal. The transient characteristics of the impact response signal on a plate structure can be effectively estimated through the time-frequency analysis techniques

There are three different types of time-frequency analysis techniques in popular such as STFT(Short Time Fourier Transform), CWT(Continuous Wavelet Transform), and W-V(Wigner-Ville) distribution whose definitions and the analyses results using 6 different signal components are depicted from Figure 1 to Figure 4 as follows:.

1) STFT[4]

The STFT for signal s(t) is defined by

$$S\ (t,f) = \int_{-\infty}^{\infty} h^{*}(\tau - t) s(\tau) e^{-j2\pi f\tau} d\tau \qquad (1)$$

where,

$h(\tau)$: window function at time τ

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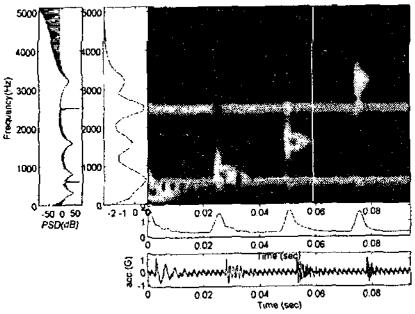

Fig. 1 Example of STFT

As shown in Figure 1, if the size of the moving window is fixed, the time and frequency resolution is not controlled in the time-frequency domain. Thus the time-frequency resolution should be trade off for the analysis of a non-stationary signal.

2) CWT[4]

This method is being popularized in various engineering fields since it is a linear transform analogous to the STFT but has more useful characteristics than the STFT. The CWT is defined as

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

where, the function $\Psi(t)$ is called the mother wavelet which is expressed by

$$\psi(t)=Ae^{-\left(\frac{t-b}{a}\right)^{2}/\sigma^{2}}e^{j2\pi\frac{f_0}{a}(t-b)} \qquad (3)$$

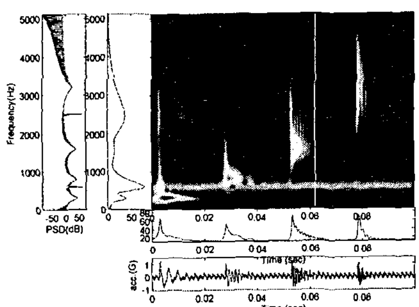

Fig. 2 Example of CWT

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 between the CWT and the STFT is that the effective duration and bandwidth of the STFT are independent of the analysis frequency, but the effective duration of the CWT is inversely proportional to the frequency and the bandwidth is proportional to the frequency. As illustrated in Figure 2, we can discriminate between the two techniques more clearly. In case of the CWT, the frequency resolution is well at low frequency but the time resolution becomes well at high frequency.

3) WVD[5]

In contrast to the above methods, WVD is a quadratic bi-linear transform and defined as

$$W(t,f)=\int_{-\infty}^{\infty}z\left(t+\frac{\tau}{2}\right)z^{*}\left(t-\frac{\tau}{2}\right)e^{-j2\pi f\tau}d\tau \qquad (4)$$

where,

$z(t)$: Analytic function of the signal $s(t)$.

The WVD has many desirable properties including the fact that it can yield good time frequency resolution. However, its direct application is limited by the fact that it generates cross-terms. Specifically the WVD of a signal a(t)+b(t) contains components due solely to a(t) and b(t), referred to as the auto-terms, with an additional interference term arising because of the interaction of a(t) and b(t). Hence applying a two dimensional low pass filter to the WVD reduces cross-terms, relative to the auto-terms. The general form of a bilinear time-frequency representation(it is also called as a smoothed WVD) is

$$W_S(t,f)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\Phi(\xi,\tau)z\left(u+\frac{\tau}{2}\right)z^{*}\left(u+\frac{\tau}{2}\right)e^{-j2\pi(\xi t+f\tau-\xi u)}d\xi du d\tau \qquad (5)$$

where,

$\Phi(\xi,\tau)$: smoothing function

Figure 3 and Figure 4 are the results of the WVD and the smoothed WVD by using exponential smoothing function, respectively. It is revealed that the smoothed WVD becomes a good solution for the higher resolution in both time and frequency domain to accurately estimate the TOAD.

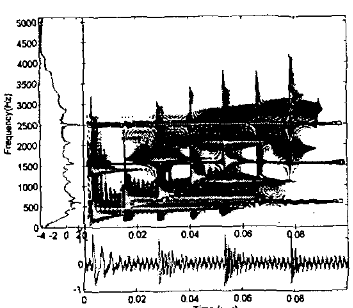

Fig. 3 Example of WVD

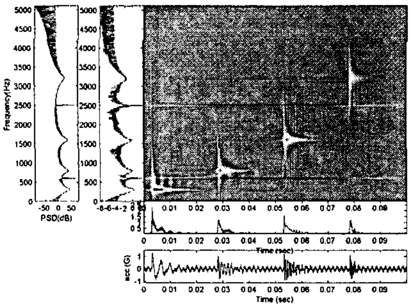

Fig. 4 Example of Smoothed WVD

3. Application to Impact Source Localization

From the above discussions, it can be stated that the arrival time of the dispersive wave will be more easily identified through the two dimensional time-frequency analysis than the conventional time domain analysis.

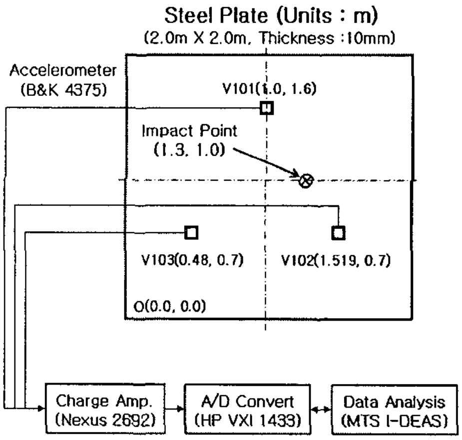

Fig. 5 Schematic of Experimental Set-up

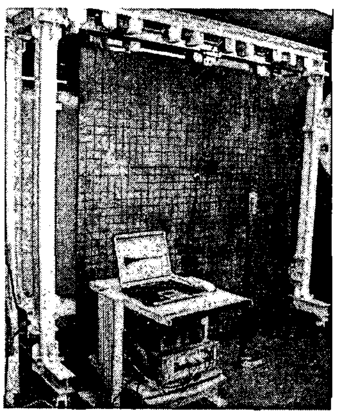

Fig. 6 Photo of Test Facility

An experiment has been performed to investigate the validity of the time-frequency technique for the location estimation of the impact source on a plate model Figure 5 and Figure 6 show the locations of the impact point and the acceleration sensors in the plate and the experimental setup. The impact is generated by dropping a small steel(around 20 g) ball from 10 cm above the plate surface.

The measured time signals from the accelerometers are displayed in Figure 7. The analyzed time-frequency distributions of the signals using the smoothed WVD are illustrated in Figure 8. As shown in Figure 8, the TOAD corresponding to each frequency component of the propagating wave group by the impact could be more easily identified in the time-frequency domain than the time domain. Based on the calculated group velocity data the impact location is estimated using a triangulation methodology and compared to the result of the conventional time domain technique as shown in Figure 9 and Figure 10, respectively. Both are in good agreement with the true impact point. However, it is apparent that the result of the smoothed WVD is more accurate than that of the time domain method.

The same localization procedure has been implemented to the noisy signals which have been made by mixing the above mesured signals with the gaussian random noise which is illuatrated in Figure 11. In this case, no reliable localization is possible in the conventional time domain analysis. It is revealed that the smoothed WVD technique still provides a useful means for the impact location estimation even in a noisy environment as shown in Figure 12 and Figure 13. Therefore, it is expected that the reliability of the location estimation could be enhanced when the proposed time-frequency method is introduced to the localization problem on the plate type structure.

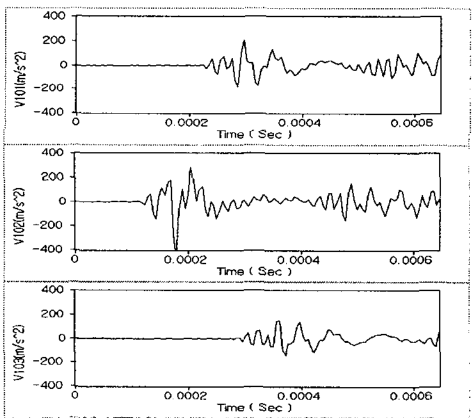

Fig. 7 Time Signals without Noise

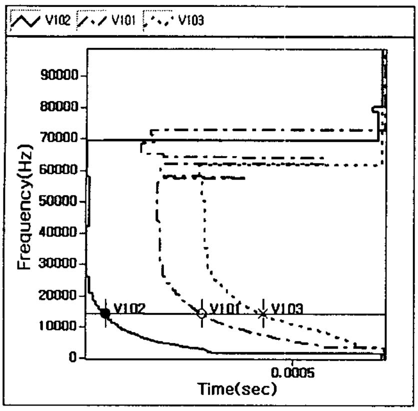

Fig. 8 Results of Smoothed WVD without Noise

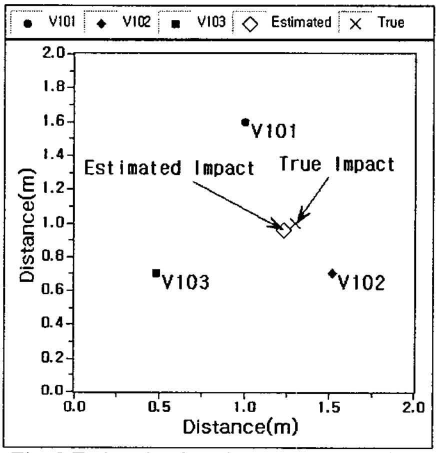

Fig. 9 Estimation by Time Domain Method (Error Range: 76mm)

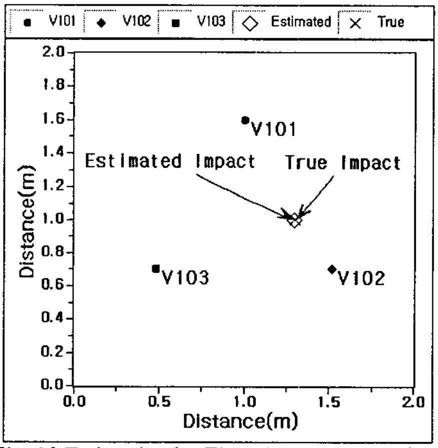

Fig. 10 Estimation by Time-Frequency Method (Error Range: 7mm)

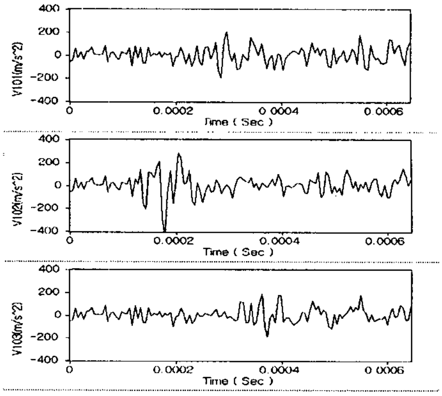

Fig. 11 Time Signals with Noise

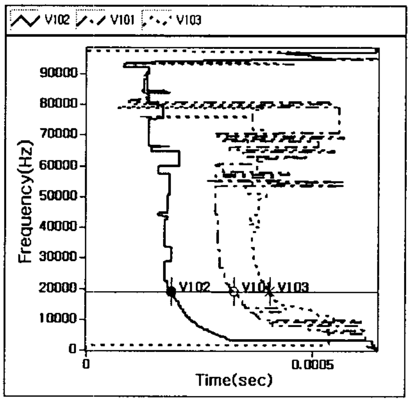

Fig. 12 Results of Smoothed WVD with Noise

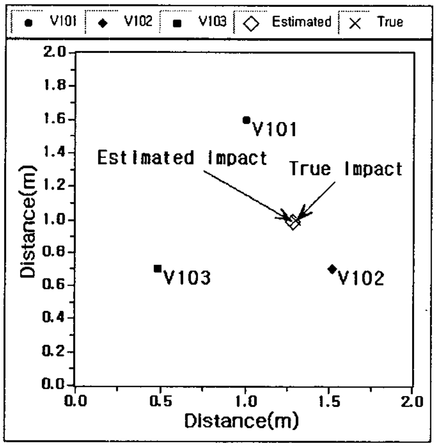

Fig. 13 Estimation by Time-Frequency Method with Noise(Error Range: 20mm)

4. Conclusions

The time-frequency methods such as STFT, CWT and WVD are expected to be more useful than the conventional time domain analysis for the impact localization problem on the plate type structure. The smoothed WVD technique is more applicable to reliably estimate the impact source location than other time-frequency techniques.

Acknowledgement

This work is supported by Korea Ministry of Science and Technology

References

(1) Kryter R.C. and Shahrokhi F., Summary of Studies on Methods for Detecting Locating, and Characterizing Metallic Loose Parts in Nuclear Reactor Coolant System, U.S. Nuclear Regulatory Commission Report NUREG/CR-2344, 1981.

(2) Olma B.J., Source Location and Mass Estimation in Loose Parts Monitoring of PWRs, Progress in Nuclear Energy 15, 583, 1985

(3) T. Tsunoda et al, Studies on the Loose Part Evaluation Technique, Progress in Nuclear Energy 15, 569, 1985

(4) F. Hlawatsch and , G.F. Boudreaux-Bartels, Linear and Quadratic Time-Frequency Signal Representations, IEEE SP Magazine 21, 1992

(5) L. Cohen, Time-Frequency Analysis, Prentice Hall PTR 1995

(6) L. Gaul and S. Hurlebaus, Identification of the Impact Location on a Plate using Wavelets, Mechanical Systems and Signal Processing 12, 783, 1997

(7) J-H Park and J-H Lee, Application of Continuous Wavelet Transform to the Impact Location Estimation of the Loose Parts Monitoring System (LPMS), International Journal of Nuclear Energy Science and Technology, To be published.