Adaptive Time-Frequency Distribution for Monitoring the Abnormal Conditions of Machinery in NPP

[a] C.K. Lee, [a] G.Y. Park , [a] J.T. Kim, [b] S.J. Lee
a Korea Atomic Energy Research Institute, b Chungnam National University
cklee1@kaeri.re.kr

1. Introduction

In Korea there are over 20 nuclear power plants (NPP) that are operating and being constructed and some of them have been operated more than 20 years. As the operating time is elapsed, it is anticipated that the failures of machinery such as the valve, the pump and other rotating equipment, pipe, and etc., will be occurred frequently. While the importance for on-line monitoring of its failure is being increased. It has not been easy to implement the monitoring system due to the lack of detection and analysis technologies, the difficult installation of sensors, the economic consideration to the expensive system, and so on. Therefore it is necessary for adding these monitoring system to the NPP that the sensing and monitoring system can be simply installed, easily operated and maintained and of course should be inexpensive. In this study we propose to use the piezoelectric sensors like accelerometer, acoustic sensor, in which no additional power or no other additions are required. Also, we introduce a time-frequency distribution with an adaptive cone-kernel which is designed for on-line monitoring the abnormal conditions of machinery in NPP. This paper summarizes the design of adaptive cone-kernel time frequency distribution (TFD) and its performance.

2. Cone-kernel Time-Frequency Distribution

The general class of TFD for an analysis was introduced by Cohen.[1]

$$C_x(t,f,\phi)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\phi(t-\mu,\tau)x(\mu+\frac{\tau}{2})x^*(\mu-\frac{\tau}{2})e^{-j2\pi f\tau}d\mu d\tau \qquad (1)$$

Where *x(u)* is a time analytic signal and $x^*(u)$ is its complex conjugate. ϕ is a kernel function which determines the size and shape of the cross-term obscuring the true energy distribution. How to reduce the cross-term optimally is a key point in the TFA, and for last two decades many time-frequency distributions (TFD) with each own kernel function have been presented to reduce the cross-terms.[1] The cone-kernel distribution (CKD) proposed by Y. Zhao, et al [2] is a TFD with the best capability of suppressing the cross-term; instead, sacrificing many of desirable properties.[3] The cone kernel in the $t-\tau$ domain is represented by

$$\phi(t,\tau)=\begin{cases} g(\tau), & |\tau|\ge a|t| \\ 0, & O.W. \end{cases} \qquad (2)$$

In Eq.(2) the cone boundary parameter, a, adjusts the slopes of the cone with the constraint, $2 \le a < \infty$, and usually is set to 2 according to the finite support property. The $g(\tau)$ is a window function and it is usually represented by the Gaussian function. The discrete form of CKD is represented by [2]

$$C_x(n,f;CKD)=\sum_{k=-T}^{T}g(k)\sum_{p=-|k|}^{|k|}x(n+p+k)x^*(n+p-k)e^{-j2\pi fk} \qquad (3)$$

Where, according to the cone length T, the resolutions of time and frequency domains are traded off.

Another key point in the TFA is to reduce the computations. Regardless of many researches in TFA it has not been widely used in the real world due to its excess of computation.

3. Adaptive Cone-Kernel TFD

The adaptive optimal kernel TFD was introduced by Baraniuk and Jones in the early of 1990's,[4] and its performance measure is an energy concentration or kurtosis. The adaptive cone-kernel distribution (ACKD) was proposed by Czerwinski and Jones.[5] We also studied an ACKD, but it is a more computationally efficient adaptive method. The frequency values at a particular time step n, are calculated for each incremental step of variation of the cone length. The ACKD can reduce the computations remarkably compared other methods and makes it possible to implement on-line or real-time monitoring. Its performance measure is the normalized Shannon's entropy which is expressed as

$$E(T,n)=\sum_{m=0}^{M-1}f_N(m,n,T)\ln\frac{1}{f_N(m,n,T)} \qquad (4)$$

Where n is a time index, m is a discrete frequency index, and T is a cone length. The f_N is a normalized energy represented by

$$f_N(m,n,T) = \frac{|C_x(n,m;CKD\ \ for\ \ T)|^2}{\sum_{m=0}^{M-1}|C_x(n,m;CKD\ \ for\ \ T)|^2} \tag{5}$$

The optimal cone length T at a particular (fixed) time index is determined when the entropy is reached to the threshold entropy or has a local minimum value before reaching to the threshold entropy from the following expression.

$$E_{th} = E_{\min} + \lambda(E_{\max} - E_{\min}) \tag{6}$$

To avoid an inaccurate determination by the local minimum point, the entropy curve is smoothed by the curve smoothing technique.[6]

4. Results of the Vibration Data Analysis

Fig.1 shows an arbitrarily generated test signal that is mixed by several signals. Fig.2 shows the ACKD proposed in this paper to the test signal. The maximum search range of the cone length is given by 64 and the threshold parameter is set by λ = 0.05. The optimal values of cone length calculated in this adaptive method are shown in Fig.3. When comparing the ACKD with other TFD's shown in Fig.4, its performances are comparative. In particular the ACKD showed a better time-frequency resolution to two vertical strips for corresponding impulse signals.

5. Conclusions

It is well known that the TFA is an effective method for analyzing the noisy signals mixed with the stationary and non-stationary characteristics. The proposed ACKD as a TFA, showed better time-frequency resolution and more reduction of cross-terms compared with other TFD's. It also reduced the computations to the order of normal TFD. Therefore it is expected that the on-line or real-time failure detection of machinery in NPP can be realized to some degree. In addition, the use of simple passive sensing devices for monitoring the abnormalities of machinery is recommended considering the field environments of NPP. Finally it is believed that the ACKD can make the operation of monitoring system easy.

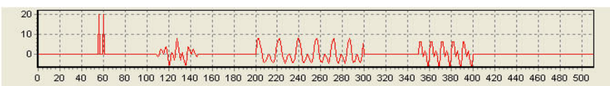


Fig. 1 Test signal

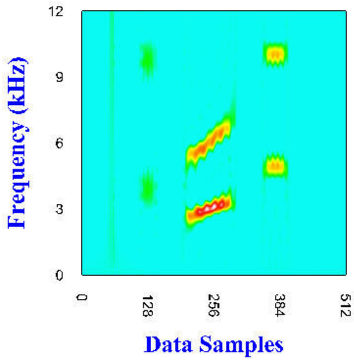


Fig. 2 ACKD for a test signal

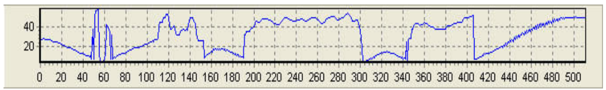
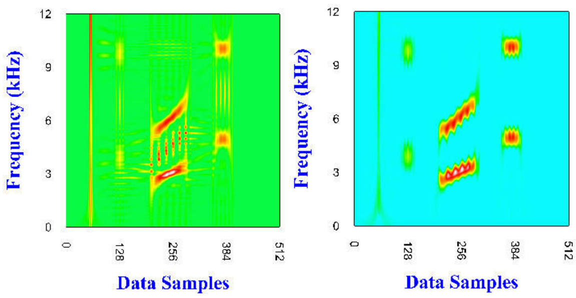


Fig. 3 Determination of optimal cone length



(a) Choi-Williams Distrbution (b) CKD

Fig. 4 TFD's for a test signal

References

[1] L. Cohen, "On a fundamental property of the Wigner distribution," IEEE Trans. On ASSP, Vol. 35, No.4, pp. 559-561, Apr. 1987.

[2] Y. Zhao, L.E. Atlas, and R.J. Marks II, "The use of cone-shaped kernels for generalized time-frequency representations of non-stationary signals," IEEE Trans. on ASSP, vol.38, no.7, pp.1084~1091, 1990.

[3] T.A.C.M. Claasen and W.F.G. Meckleubrauker, "The Wigner distribution – A tool for time-frequency signal analysis; Part I, II, III," Philips J. of Research, vol.35, 1980.

[4] D.L. Jones and R.G. Baraniuk, "A simple scheme for adapting time-frequency representations," IEEE Trans. on SP, Vol. 42, pp.3530-3535, 1994.

[5] R.N. Czerwinski and D.L. Jones, "Adaptive cone-kernel time-frequency analysis," IEEE Trans. on SP, vol.43, no.7, pp.1715~1719, 1995.

[6] B.S. Moon, "A curve smoothing method by using fuzzy sets," Fuzzy Sets and Systems, vol.96, pp.353 ~ 358, 1998.