Detection of Vibration Caused by Flow Accelerated Corrosion on the Pipes Using Cone-Shaped Kernel Time-Frequency Distribution

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1. Introduction

Pressure vessels and heat exchangers such as steam generators in the Nuclear Power Plant (NPP) have very sophisticated piping systems operating in a very aggressive erosion and corrosion environment with turbulent flow, high temperature and pressure. These adverse operating environments make a piping system very vulnerable to accelerated wear and degradation. But there is no practical way to monitor the wear and degradation during operation. In this study we analyzed the vibration signal measured by accelerometer to monitor them on the pipes. The accelerometer is convenient to install and strong to the harsh environments. For the analysis, the cone-shaped kernel time frequency distribution (CKD) is used. It is one of time-frequency analysis (TFA) methods being used in the analysis of noise and acoustic signal in recent years.[1][2] From CKD's, we can get better signature for wear and degradation on the pipe than that by the frequency analyses.

2. Data Acquisition

Moisture separator and re-heater (MSR) drains in a NPP secondary side were selected for the flow accelerated corrosion (FAC) monitoring, since MSR drains with single-phase flow have a high susceptibility to FAC. As shown in the Fig. 1, we developed a test loop to collect the vibration data for FAC. Its operating temperature (150ºC) and pressure (20 bar) are similar to the plant condition.[3] The elbow pipe and U-shaped pipe are chosen as test specimens to maximize the effect of FAC, that is, vibration. A 3-axis accelerometer is used to detect the vibration on the pipe and its sampling rate is 20 KHz.

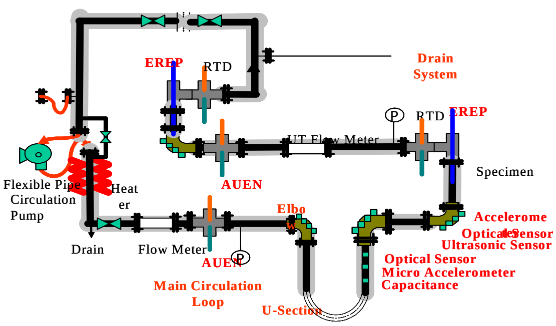
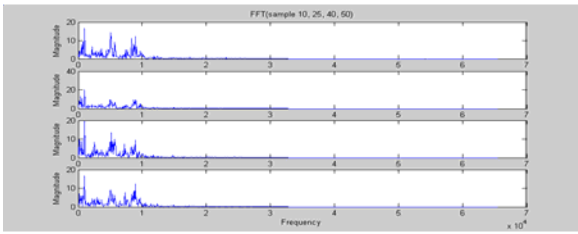
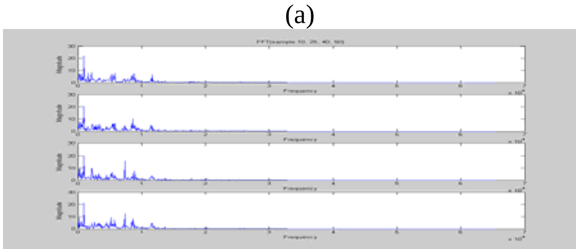


Fig.1 Test Loop for FAC Simulation

The acquisition data were analyzed by Fourier transform, MUSIC and auto regressive method. The results in the Fig. 2 showed that there were small changes in the frequency location and amplitude when the pipe thickness is changed, but those were not enough to identify the degree of wear and degradation on the pipe. So it required another analysis method.



(a)



(b)

Fig. 2 Spectra for corrosion (a) and normal (b)

3. Cone-shaped Kernel Time Freq. Distribution

The TFA is effective to the analysis of time-varying and transient signals, which represent the intensity of energy for a signal in time-frequency domain. The general class of time frequency distributions (TFD) for analysis was introduced by Cohen.[4]

$$C_f(t,w,\phi) = \frac{1}{2\pi}\iiint e^{j(\xi\mu-\tau\omega-\xi t)}\,\phi(\xi,\tau)\,f(\mu+\frac{\tau}{2})\,f^*(\mu-\frac{\tau}{2})\,d\mu\, d\tau\, d\xi \qquad (1)$$

where $f(\mu)$ is a time analytic signal and $f^*(\mu)$ is its complex conjugate. ϕ is a kernel function which determines the size and shape of cross-term obscuring the true energy distribution over the time and frequency.

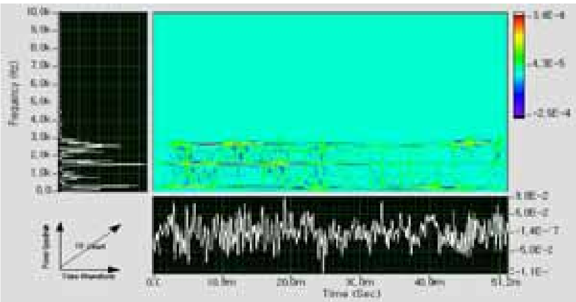
How to reduce the cross-term optimally is a key point in the TFA. CKD is one of TFA methods developed to reduce the cross-terms. In CKD, the choice of scaling factor should be optimized for application, which is a signal dependent. In addition, An exponential distribution (ED) is used to verify CKD. The kernel functions for CKD and ED are respectively

$$\phi(\xi,\tau) = g(\tau)\left|\tau\right|\frac{\sin(a\xi\tau)}{a\xi\tau} \quad (2)$$

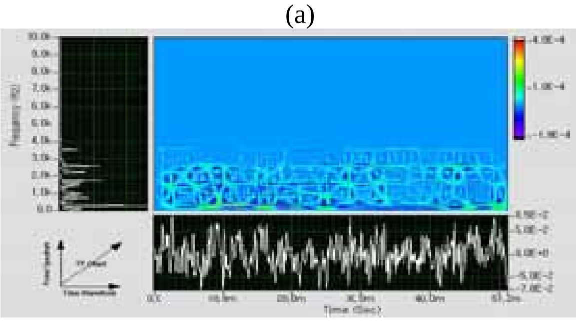
$$\phi(\xi,\tau) = e^{(-\xi^2\tau^2/\sigma)} \quad (3)$$

4. Results of Vibration Data Analysis

CKD's in the Fig. 3 are represented with a software provided by National Instruments Corp. We calculated them with changing the scale factor until getting the optimal distribution for evaluation. DC bias from the acquisition data is eliminated by averaging method to reduce the interference on CKD's. The data for analysis are arbitrary sampled and the length of each sample is



(a)



(b)

Fig. 3 CKD's for corrosion (a) and normal (b)

1,024 data per sample. And ED in the Fig. 4 provides 3-dimensional distribution, in which x-axis is time, y-axis frequency and z-axis amplitude. From CKD's we identified the small frequency shift and some amplitude changes in the characteristic frequencies (500, 1,600, 2,700 Hz) which have the signature of vibration. This is same as the result of frequency analyses. But CKD provides one more information - the amplitude fluctuations in the instantaneous frequency of each characteristic frequency. In CKD's for corrosion, we can see peaks with some period. These peaks will be expected to occur with shorter period when corrosion proceeds deeply. In addition, ED verify the peaks and their fluctuation easily in each characteristic frequency.

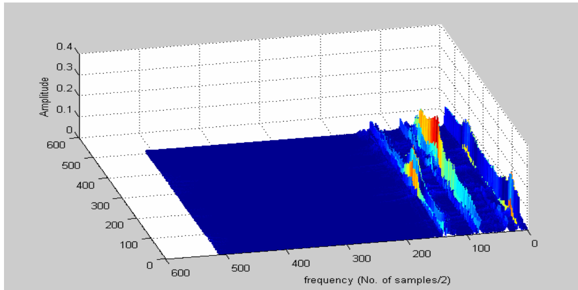


Fig. 4 ED for corrosion

5. Conclusions

The development of an on-line condition monitoring system through pertinent sensors is highly desirable to evaluate the severity of FAC phenomenon in the piping components and to take actions before excessive degradation. The result by CKD can provide the more information for evaluation of the integrity of piping component, moreover under the condition that misunderstanding may lead to the loss of economy.

Acknowledgements

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