Diagnosis of Bearing System using Minimum Variance Cepstrum

Jeong-Han Lee[a], Young-Chul Choi[a], Jin-Ho Park[a], Won-Hyung Lee[b], Chan-Joong Kim[c]
[a] *Korea Atomic Energy Research Institute, 150 Duckin Dong Yusung Gu, Daejuon city, Korea, 305-353*
[b] *Korea Hydro & Nuclear Power Co. , Ulchin Nucelar power site(Unit3&4) #84-4 Uljin, Gyeong-buk, Korea. 767-701*
[c] *Korea Hydro & Nuclear Power Co. 167 Samseong-dong, Gangnam-hu, Seoul 135-791, Korea*

1. Introduction

Various bearings are commonly used in rotating machines. The noise and vibration signals that can be obtained from the machines often convey the information of faults and these locations. Monitoring conditions for bearings have received considerable attention for many years, because the majority of problems in rotating machines are caused by faulty bearings. Thus failure alarm for the bearing system is often based on the detection of the onset of localized faults.

Many methods are available for detecting faults in the bearing system. The majority of these methods assume that faults in bearings produce impulses. Impulse events can be attributed to bearing faults in the system. McFadden and Smith [1] used the bandpass filter to filter the noise signal and then obtained the envelope by using the envelope detector. D. Ho and R. B Randall [2] also tried envelope spectrum to detect faults in the bearing system, but it is very difficult to find resonant frequency in the noisy environments. S. -K. Lee and P. R. White [3] used improved ANC (adaptive noise cancellation) to find faults. The basic idea of this technique is to remove the noise from the measured vibration signal, but they are not able to show the theoretical foundation of the proposed algorithms. Y.-H. Kim et al. used a moving window [4-5]. This algorithm is quite powerful in the early detection of faults in a ball bearing system, but it is difficult to decide initial time and step size of the moving window.

The early fault signal that is caused by microscopic cracks is commonly embedded in noise. Therefore, the success of detecting fault signal is completely determined by a method's ability to distinguish signal and noise.

In 1969, Capon[6] coined maximum likelihood (ML) spectra which estimate a mixed spectrum consisting of line spectrum, corresponding to a deterministic random process, plus arbitrary unknown continuous spectrum. The unique feature of these spectra is that it can detect sinusoidal signal from noise [7]. Our idea essentially comes from this method. In this paper, a technique, which can detect impulse embedded in noise, is introduced. The theory of this technique is derived and the improved ability to detect the faults in a ball bearing system is demonstrated theoretically as well as experimentally.

2. BASIC THEORY OF MINIMUM VARIANCE CEPSTRUM

First, we defined [8]

$$F_{MVc} = \frac{1}{\mathbf{e}^H (\mathbf{w}^H \mathbf{R}_x \mathbf{w})^{-1} \mathbf{e}} \tag{1}$$

where $\mathbf{R}$ is the autocorrelation matrix, $\mathbf{g}$ is the filter coefficient, the superscript H denotes the Hermitian operation, and $\mathbf{e}_i = \left[1, e^{j\tau_i}, \cdots, e^{jp\tau_i}\right]^T$.

Because the method minimizes the variance of the signal power at the cepstrum domain, it is suggested to be called as 'minimum variance (MV) cepstrum'.

When a fault in one surface of a rolling element bearing strikes another surface, it produces an impulse which may resonances in the bearing as shown in Fig. 2. As the bearing rotates, these impulses will occur periodically with a frequency which is determined uniquely by the location of the defect.

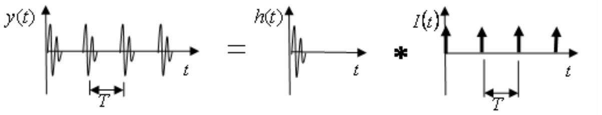


Fig.1 *The fault signal of the rotating machines can be expressed convolution between fault signal and impulse trains. Where $y(t)$ is bearing fault signal, $h(t)$ is an impulse response function, $I(t)$ is periodic impulse train and T is impulse period.*

2. Experiments and results

To verify the proposed method, various experiments have been performed for ball bearing elements. The faults were made artificially using the electric drill pen (Fig. 2(a)) and the file (Fig. 2(b))

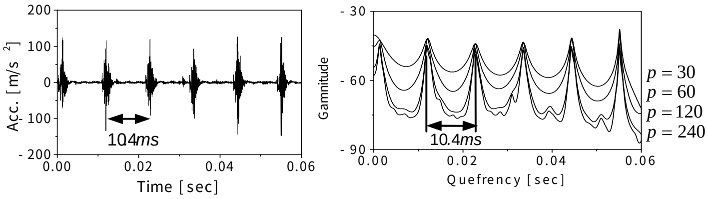
The rotational speed of the bearing is 1800 rpm. An accelerometer (B&K type 4371) is attached the surface of the bearing system. Measured signals are digitized by a data acquisition system and stored in DAT recorder. The measured acceleration signal is digitized by the sampling rate of 40 kHz.

Fig. 3 shows the signal characteristics of a ball bearing system which has a single fault on the outer race. As shown in the result of the minimum variance cepstrum

(Fig. 2(a)), fault period (To) which corresponds to 10.4 ms is clearly detectable

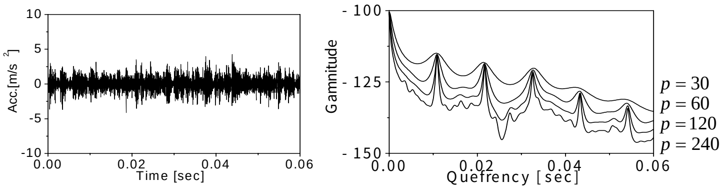
(a) (b)

Fig. 2 *Single inner race fault of ball bearing (a) fault length=6mm, fault width=0.42mm, fault depth=0.0152mm, (b) fault length=6mm, fault width=0.08mm, fault depth=0.0034mm*



(a) (b)

Fig. 3 *Analyzed result of bearing with single fault in the outer race; fault length = 6mm, fault width=0.34mm, fault depth=0.0248mm. (a) Fault signal in the outer race (Number of data N=4096,* Δt *=0.0015ms, pulse period,* T_o*=10.42ms). (b) Minimum variance cepstrum*



(a) (b)

Fig. 4 *Analyzed result of bearing with single fault; Fault length= 6mm, fault width=0.08mm, fault depth=0.0034mm as shown in Fig.3 (b). (a) Fault signal (Number of data N=4096,* Δt *=0.0015ms, pulse period,* T_o*=10.42ms). (b) Averaged minimum variance cepstrum of 60 fault signals*

Fig. 3(a) shows quite clear periodicity in the time data. Because the faults were made artificially, the signal had a quite high signal to noise ratio. These results can't demonstrate the performance of the proposed method. Fig. 4(a) shows the vibration signal of the ball bearing system as shown in Fig.2(b). The signal does not show the periodicity due to faults. In spite of low signal to noise ratio, the proposed method easily detect the faults embedded in noise as shown in Fig.4 (b). The characteristic fault period make it possible to detect the presence as well as the localization of the faults. This is because pulses will occur with the period which is determined uniquely by the location of the defect. The experimental result demonstrates that the proposed signal processing method is able to detect the presence and types of faults embedded in noise.

3. Conclusion

We have introduced the technique for the detection of the impulse embedded in noise, which is proposed to apply to the fault detection of a ball bearing system. Fault detection of ball bearing systems has been based on the idea to detect periodicity of impulse train due to faults. To test the performance of this technique, various experiments have been performed for ball bearing elements that have man made faults. Results show that minimum variance cepstrum can easily detect the periodicity due to faults and also show the pattern of excitation by the faults. The technique is also applicable to plant, such as reactor coolant pump, and turbine diagnosis.

REFERENCES

[1] P. D. Mc Fadden and J. D. Smith, “Model for the vibration produced by a single point defect in a rolling element bearing,” *Journal of Sound and Vibration* **96**, pp. 69-82, 1984

[2] D. Ho and R. B. Randall, “Manifestations of bearing fault vibrations in gearboxes,” *Sixth International Congress on Sound and Vibration* ,2943-2950,1999

[3] S. K. Lee and P. R. White, “The Enhancement of Impulsive Noise and Vibration Signals for Fault Detection in Rotating and Reciprocating Machinery,” *Journal of Sound and Vibration* **217** (3), pp. 485-505, 1998

[4] Y.-H. Kim, B.-D. Lim and W.-S. Cheoung, “Fault detection in a ball bearing system using a moving window,” *Mechanical systems and Signal Processing* **5**, pp. 461-473,1991

[5] W. J. Staszewski and G. R. Tomlinson, “Local tooth fault detection in gearboxes using moving window procedure, ” *Mechanical systems and Signal Processing* **11(3)**, pp. 331-350,1997

[6] J. Capon, “High-Resolution Frequency-Wavenumber Spectrum Analysis,” *Proceedings of the IEEE, Vol. 57, No. 8, August*, pp.1408-1419, 1969.

[7] Peter J. Sherman, “On the Family of The ML Spectral Estimates for Mixed Spectrum Identification,” IEEE Transactions on Signal Processing. Vol. 39, No. 3, march, pp.644-65, 1991

[8] Y.-C. Choi and Y.-H. Kim, "Detection of impulse signal in noise using a minimum variance cepstrum-theory," Korean Society for Noise and Vibration Engineering, Vol.10(3) , pp.642-647, 2000