Research of Two Different Impulsive Faults of Rolling Element Bearing

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Abstract. Fans and pumps are key machines in process industries such as petrochemical and petroleum industries. Their faults can be catastrophic and result in costly downtime. Bearing fault is almost the most common fault of fans and pumps as rolling element bearings are widely used in these machines. Hence, condition monitoring and diagnosis of bearings are important. Two different impulsive faults of bearings have been observed and studied in previous research. The first fault presents very clear impulsive symptom in envelope spectrum, but the bearing can work for a long time. The other fault shows relatively indistinct symptom, but the bearing will break down in a short time. To overcome the problems of inaccurate diagnosis, a combinational approach based on an impulsive energy indicator and traditional enveloping analysis is proposed in this paper. This approach discriminate these two faults well and can support the maintenance decision for the machines with rolling element bearings.

1. Introduction
In process industries such as petrochemical and petroleum enterprises, many kinds of fans and pumps are key machines. These key machines contains, for example, booster pumps in gas pipelines, oil transfer pumps in oil production platforms, and air blowers (Fans) in catalytic cracking units. In these machines, rolling elements bearings and gearboxes are widely used and easy to wear.

Rolling element bearing fault is one of the main causes of failures in machinery and such fault can be catastrophic, resulting in costly downtime. In order to prevent these kinds of faults from happening, various bearing condition monitoring techniques have been developed. Vibration signal analysis is the main approach for bearing condition monitoring. The signals of rolling bearings faults are usually transient and modulated by high-frequency carrier signals. One of the most popular signal processing approaches for bearing fault diagnosis is demodulation or enveloping methods. In this technique, the high-frequency resonance technique is always applied to the vibration signal demodulation. This
technique takes advantage of the absence of low-frequency mechanical noise to demodulate a vibration signal, therefore, it provides a low-frequency demodulated signal with a high SNR[1]. In order to implement the high-frequency resonance technique, the originally measured vibration signal is usually filtered by a classical high-pass filter (CHPF) at first. Then, the filtered signal is processed by Hilbert transform. The demodulated signal or the envelope is the modulo of the transformed signal. If cut-off frequency was chosen properly and the signal was measured correctly, the bearing characteristic frequencies (BCFs) can be found in the spectrum of the envelope. The high-frequency resonance technique is called CHPF based enveloping in this paper.

For the use of envelope technique, vibration is measured by many kinds of sensors mounted on the monitored machine. Vibration sensors like accelerometers should be mounted on the position close to the bearing. Following this basic principle, the typical bearings and measurement points of a pump or a fan machine set are shown in Figure 1.

![Figure 1. Bearings and the measurement points of a Pump or Fan driven by motor or turbine (An outboard structure example here).](image)

2. Method

There are several methods for envelope analysis of vibration signals. In this study, Hilbert transform is used to solve the problem as it has been proven to be simple and effective. The algorithm of Hilbert transform is defined as follows[2]:

\[
\hat{f}(t) = H\{f(t)\} = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{f(\tau)}{t-\tau} d\tau
\]  

(1)

Where \( t \) is time, \( f(t) \) is the time-domain signal in a certain frequency band, \( H\{f(t)\} \) is the Hilbert transform of \( f(t) \). The envelope signal \( Env(t) \) is the modulo of the analytic signal:

\[
Env(t) = \left| \hat{f}(t) + j \cdot \hat{\bar{f}}(t) \right|
\]  

(2)

Figure 2 shows the scheme of CHPF based enveloping.
An indicator variable IVE (Impulsive Vibration Energy) which stands for the severity of impulsive vibration caused by bearing faults is also defined in this paper:

$$IVE = \int_0^T Env^2(t) dt$$  \hspace{1cm} (3)

Where \(T\) is the time duration of the signal \(Env(t)\). Usually, \(T\) equals to the collected original acceleration signal’s time duration.

In the following sections, an experimental data study and a real-life engineering case study are conducted to verify the proposed method.

3. Experimental Data Study

In this section, vibration signals of the whole bearing life are analyzed by the proposed method. The IVE trend of these signals is produced and some conclusions are drawn for engineering application.

3.1. IMS Bearing Vibration Data Description

The vibration signals used in this study are obtained from the bearing data of NSF I/UCR Center on Intelligent Maintenance Systems (IMS)[4]. Four bearings were installed on one shaft. The rotation speed was kept constantly at 2000RPM. 6000lb radial load was placed onto the shaft and bearing by a spring mechanism. All bearings were forced lubricated. On each bearing two (vertical X/Horizontal Y) accelerometers were installed. Figure 3 shows the experimental rig and measurement points. All faults occurred after running time exceeding the designed lifetime of the bearings that is more than 100 million revolutions. Data were sampled at 20 KHz by a computer-based data acquisition (DAQ) system.

![Diagram](image_url)
In this paper, we used the data of Bearing 3 with the duration about 150 hours before its complete failure.

3.2. IMS Bearing Data Analysis

During the 150 hours before bearing 3 was completely damaged, 380 acceleration signals were collected. Every signal was processed according to the framework shown in Figure 2 (5 KHz high-pass filter was adopted). Hence, 380 IVEs and envelope spectrums were obtained. IVE is plotted as a function of time, see Figure 4.

The time-variation pattern of IVE includes two main processes, P1 and P2, which illustrated in Figure 4. At P1, IVE increased firstly, which corresponds with the initial defect in the bearing. At P2, IVE increased sharply, which corresponds with the final breaking of the bearing. The envelope spectrums are also plotted as a function of time in Figure 5. At P1 and P2, envelope spectrums also changed distinctly.

From above analysis, we can find that IVE and envelope spectrum are efficient for bearing fault prognostics.
4. Case Study

The IVE and envelope spectrum trends were used in fans and pumps condition monitoring and prognostics. Two cases were studied here to illustrate the efficiency of the proposed method.

4.1. A pump bearing fault with stable IVE and envelope spectrum

Figure 6 shows a pump driven by a steam turbine through a gearbox which runs in a petroleum refining plant. This pump provides crude oil for the next process step, and it is one of the key machinery in the petroleum refining industry; hence it is monitored by off-line instruments and accelerometers. This pump is supported by two radial rolling element bearings and one thrust bearing. The seventh bearing (Brg7) presented very stable IVE (Figure 7). However, very clear and sharp BPFO (Bearing Pass Frequency of Outer Race) and its harmonics are shown in envelope spectrum (Figure 8). The envelope spectrum implies that the bearing has an obvious defect on its outer race. This phenomenon has lasted over 12 months and the bearing is still working now. According to the
experimental analysis results in section 3.2, Brg7 is under the condition between “P1” and “P2” and does not reach its fatigue limit. Hence, the maintenance advices recommend 1) keeping good lubrication, 2) not shutting down the pump or replacing Brg7.

**Figure 6.** A turbine driven centrifugal pump and the measurement points (An accelerometer was mounted on the bearing casing close to Brg7 and vibration data was collected by an offline instrument).

**Figure 7.** IVE trend of Brg7 (the pump in Figure 6).

**Figure 8.** Envelope spectrum of Brg7 (the pump in Figure 6).

4.2. *A fan bearing fault with increasing IVE and changing envelope spectrum*

Figure 9 shows an air blower fan driven by an induction motor which runs in the same petroleum refining plant of section 4.1. This fan provides air for the next process step and is also one of the key machinery in petroleum refining industry; hence it is monitored by off-line instruments and accelerometers as well. This fan is supported by two radial rolling element bearings and one thrust bearing. The third bearing (Brg3) presented increasing trend of IVE (Figure 10). Neither very clear
BCFs nor harmonics are shown in envelope spectrum at the beginning time P1 (Figure 11 (a)). About two weeks later, very clear cage frequency (Fundamental Train Frequency, FTF) and its harmonics showed up in the envelope spectrum. The bearing had an obvious defect on its cage, and the defect was under quick development. This bearing will totally break down soon. Hence, the maintenance advices were shutting down the fan immediately and replacing Brg3. After replacing the Brg3 and restarting the fan, the IVE was near to zero (Figure 10, P3), which means that there is almost no impulsive defect and no impulsive energy.

**Figure 9.** An induction motor driven air blower fan and the measurement point (An accelerometer was mounted on the bearing casing close to Brg3 and vibration data was collected by an offline instrument).

**Figure 10.** The IVE trend of Brg3 (the fan in Figure 9).
5. Conclusions

Acceleration vibration monitoring and enveloping analysis are helpful for the prognostics of the rolling element bearing in fans and pumps. The IVE proposed in this paper is proven an efficient symptom for impulsive vibration faults such as bearing defects. The experimental data study and engineering cases illustrate that the approach of combination of IVE trend and envelope spectrum trend is easy to use. The results show that the approach proposed in this paper is valuable for the prognostics of fans and pumps, and it can be a useful tool for supporting the maintenance decision of the machines with rolling element bearings.

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