Frequency domain analysis in condition monitoring- a review

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Abstract

Rotating components are important element in any machine as most of the failures are happening due to rotating components. Therefore, rotating components needs to be inspected for their faults regularly to verify its health so that shutdown of the machine should not occur during its repair. This chapter aims to review the vibration-based frequency-domain techniques used in the detection of rotating components faults. After the review of the various frequency-domain techniques, the techniques were compared to draw the advantage of using them in vibration analysis. The main advantage of using frequency-based vibration analysis techniques is that one need not to dis-mental the rotating components for the purpose of inspection. In addition to that important frequency contents of the signal can be extracted with the energy level also through using these techniques the time domain information is completely lost

Keywords: Condition monitoring, vibration analysis, rotating machinery

1 Introduction

In this technique data is presented in terms of frequency and its magnitude. Frequency domain techniques are used when information of frequency in signal is important to identify cause of periodicity. Some of the frequency domain techniques for analysis of vibration/acoustic signal are discussed below.

1.1 Spectrum analysis

The classic technique for spectrum analysis is the Fourier transform, which breaks the signal into sinusoidal (i.e. smooth oscillating) components. The utility of the Fourier transform (FT) lies in its ability to convert a time domain signal into its frequency contents [Stein and Weiss, 1971]. It is computed as inner products of the signal with sine wave basis functions of infinite duration. For a continuous-time signal, $x(t)$, the Fourier transform, $X(f)$ is expressed as:

$$X(f) = \int_{-\infty}^{+\infty} x(t).e^{-i2\pi ft}\,dt \tag{1.5}$$

here f represents global frequency and t denotes the time. The signal can then be analyzed for its frequency content because the value of the transformed function represents the contribution of sine and cosine function at each frequency. The $x(t)$ can be obtained from its Fourier transform in the following manner:

$$x(t) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} X(f).e^{i2\pi ft}\,dt \tag{1.6}$$

Plot for a typical raw signal of defective bearing in time domain is shown in Figure 1.1 and its FFT i.e. in frequency domain is shown in Figure 1.2.

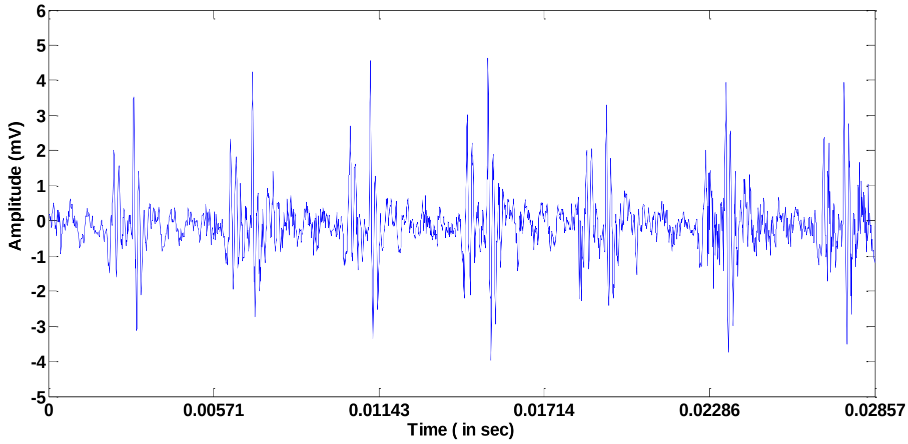

Figure 1.1: A typical time domain signal for defective bearing.

The benefit of the Fourier spectrum is that each rotating element in a machine generates particular frequencies which can be used to recognize defects in machines [Eshleman, 1983]. The spectrum indicators such as root mean square levels can show

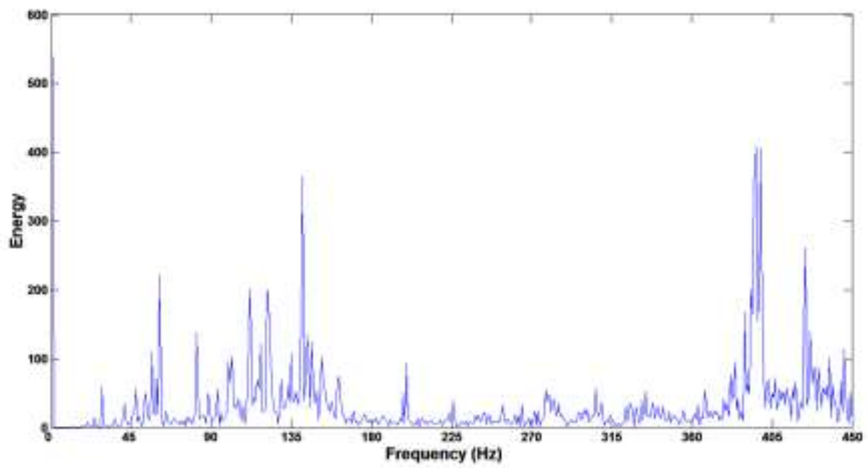

Figure 1.2: FFT for defective bearing signal shown in Figure 1.1.

the difference between the current spectrum and the baseline spectrum which can be used to point out the overall performance of machinery. In order to simplify its application narrow bandwidth spectrum may be replaced by a constant percentage bandwidth spectrum. Although, spectrum analysis is one of the best vibration indicators of machine condition but with a small change in speed, the position of the peaks may change and give incorrect results. To overcome this problem, a new spectrum called the synthesized spectrum may be used [Martin, 1987]. Using spectrum analysis, detection of the fault frequencies and fault conditions is some time difficult. Moreover, time-based information is completely lost in spectrum analysis and it is difficult to give information about the time when these frequency components occurred.

1.2 Waterfall plot

The Waterfall plot basically shows spectrum of signal at successive intervals of time. It is collected form of Fast Fourier Transform (FFT) magnitude spectrums. Sometimes it is also called a cascade plot. This method is used to examine sub synchronous and super-synchronous components of a machine [Trevillion et.al, 1989]. The advantage of using this plot is that changes in speed may be identified visually. This method is specially applied to certain types of faults such as oil whirl/whip, cracked shaft and rubs. Although, waterfall display is useful but it does not give accurate result when there is fast change in speed of the rotor [Leuridan et.al, 1994].

1.3 Holospectrum

This holospectrum gives the information about peak frequency, amplitude along with the phase relationships [Liangsheng et.al, 1989]. For complete information, vibrations of a rotor are measured by two accelerometers. Holospectrum is created by a simple vector in each frequency in the form of circle, line and ellipse placed on the frequency axis. A circle is obtained if the amplitudes of two components are equal and their phases are 90^o or 270^o. For imbalance in the shaft, a circle is obtained in the rotating frequency of a shaft. A line is obtained if the phase lag between two elements of a machine is 0^o or 180^o. The slope of the line depends on their amplitude proportion. This method is seldom successful in detection of faults in rotating machinery in the presence of background noise or self excited vibrations of rotating shaft.

1.4 Cascade holospectrum

A cascade holospectrum diagram can be constructed from the two-dimensional holospectrurn using the cascade spectrum diagram principle. The cascade holospectrurn diagrams may provide more information about the transient events of a machine [Collacott, 1979]. In addition to the cascade diagram, the cascade holospectrum gives the phase relations between the two accelerometers. Inaccuracy in result occurs when signal is dominated by noise, surface quality, self excited low frequency vibration and rapid variation in speed of the rotating shaft.

1.5 Bode and polar plot

The bode plot is a graphical representation of transfer function of liner, time variant system versus frequency to show its (system) frequency response. A typical representation of this plot is given in Figure 1.6. If represented in polar coordinate system (in the Nyquist plot), the gain of the transfer function is plotted on radial coordinate and its phase is plotted as an angular plot [NI, 2005].

Although, these plots are useful in the field of balancing problems, mode shape of the rotor, cracked shaft detection and rubs [Trevillion et al., 1989], yet they are of little use in the case of machine monitoring.

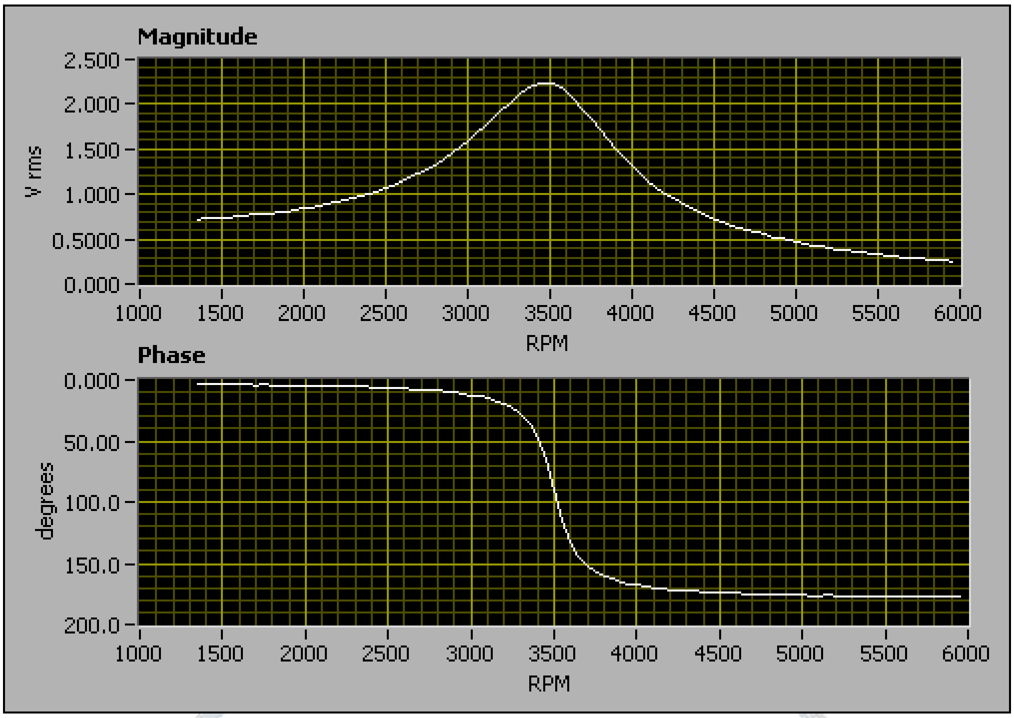

Figure 1.6: A typical Bode plot for a typical rotor during run-up.

1.6 Cepstrum analysis

The cepstrum is inverse Fourier Transform of the logarithm of the correlation function and represented as [Martin, 1987]:

$$C(\tau) = FFT^{-1}[\log G_{xx}(f)] \tag{1.7}$$

where, $G_{xx}(f)$ is frequency dependent correlation function.

It shows rate of change in different spectrum bands to highlight periodicities in the spectrum, in the same manner spectrum is used to highlight periodicities in the time waveform. The harmonics in the spectrum are summed into one peak in the cepstrum analysis making it easier to identify, and observe trends of specific fault frequencies. For a defective bearing cepstrum plot is shown in Figure 1.7.

The ceptrum analysis is useful in bearing and gear-box analysis [Archambault, 1989]. However, the Cepstrum distorts the harmonics (appearing at higher frequencies) and sidebands in the higher frequencies and in this situation it may be difficult to identify the type of defect by the cepstrum analysis.

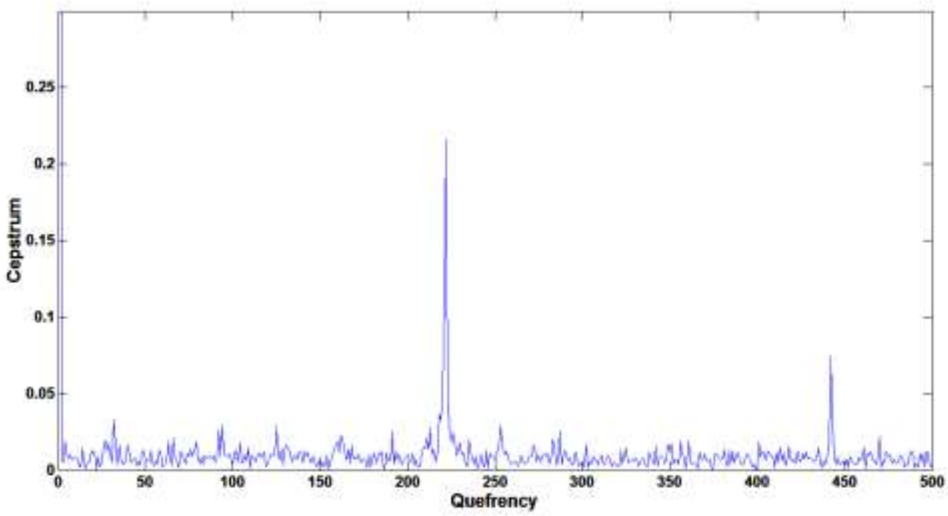

Figure 1.7: Cepstrum of the FFT shown in Figure 1.5 for defective bearing.

Conclusion

Attention has to be paid to the vibration analysis-based techniques for detecting faults in rotating components. Therefore, they need to be reviewed properly before taking decision that which technique has to be implemented. The main advantage of using appropriate technique is to detect the defect at incipient stage and hence, avoiding the shutdown of the machine. This chapter presented most common frequency-domain techniques used in the detection of rotating components faults. The techniques were compared to draw justification for their appropriateness of the condition where they have to be used. The frequency domain techniques are widely used where frequency contents of the signal have to be extracted with the energy level. This chapter will help the readers to learn that how to make use of frequency-domain based techniques as a predictive maintenance tool.

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