Chapter 22
Application of Synchronous Averaging for Detecting Defects of a Gearbox

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Abstract Condition monitoring of gearboxes in industrial settings is often based on trending vibration levels at gearmesh frequencies and sideband frequencies associated with matting shaft rotational speeds. However, it is debated on the vibration levels for setting different alarms related to the gearbox health. Another issue of controversy is what an indicator of fault severity; is it energy in gearmesh frequencies or the energies in sidebands . In this work, we analyzed vibration signature caused by gear tooth seeded faults of different levels. The data are analyzed in both time and frequency domains. The experimental study is conducted on a Machinery Fault Simulator ™ (MFS). The pinion gear in the gearbox is intentionally faulted with increasing severities, and vibration signal was collected for each case using IEPE accelerometers. Data are also obtained using a high-resolution encoder. Signals are analyzed using time synchronous averaging and traditional spectrum analysis. The results indicate that the vibration signature of a faulted bevel gear tooth is a pulse in time domain. Because of this impulse signal, strong sidebands arise in the spectrum around the mesh frequency. And the energy inside bands are better indicator of tooth defect severity.

Keywords Gearbox · Time Synchronous Averaging · Spectra · Gearmesh · Side bands

22.1 Introduction

Gearboxes are very commonly used in industry as well as in vehicles for transferring motion and power from shaft to another shaft. During their extended service lifetimes, gear teeth will inevitably be worn, chipped, or even missing under high load. Therefore, effective diagnostic methods are required in order to enhance the reliability of the entire machine before any unexpected catastrophic consequences occur. The vibration-based techniques are the most widely used since it is easy to obtain the acceleration signals using accelerometers. The gear diagnostic parameters include RMS value, crest factor, kurtosis, energy ratio, and other metrics [1]. They are all statistical methods. Standard vibration analysis is based traditional spectral analysis examining gearmesh frequencies and associated shaft speed-related sidebands.

Typically, the data are averaged using RPM averaging technique [2–4]. The RPM averaging smooth the variation about the mean but mean stays the same. Once a gearbox wears, its noise floor goes up. This makes it difficult to analyze the defects and its severity. In this work, we used time synchronous averaging to study the gearbox faults and the degradation. It is observed that when a faulted bevel gear tooth enters meshing, it produces an impulse-like signal in the time domain and the amplitude of the impulse increase with the damage. In the frequency domain, the amplitudes of pinion sidebands also increase with the severity level.

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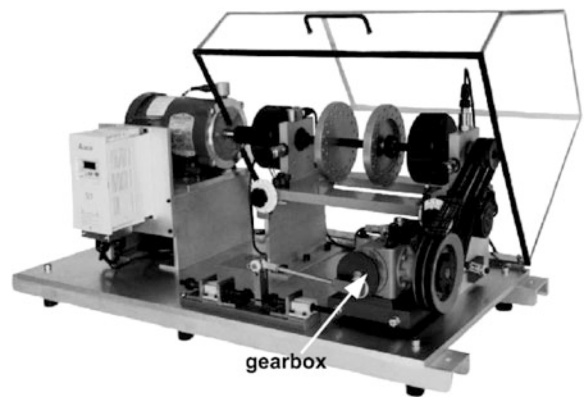
22.2 Test Setup

The experiment is conducted on a Machinery Fault Simulator ™ (MFS). The MFS and the position of the gearbox in the MFS are illustrated in Fig. 22.1.

The gearbox details are shown in Fig. 22.2a. The transmission ratio is 1.5:1. There are two straight bevel gears in the gearbox and they are shown in Fig. 22.2b. The number of teeth on the pinion is 18. The gearbox input shaft is connected to a sheave and driven by a V belt drive. The gearbox output shaft is connected with a variable brake loader. Torsional loading is applied to the gearbox using a magnetic particle brake. This is driven by a double belt drive connected to the motor shaft. The speed ratio of 2.56 was configured as a reducer. Belt tension can be adjusted using dowel tell mechanism or by pushing the lower part of the belts with a turnbuckle system. The tachometer is installed on the rotor deck with a bracket and used to measure the speed of the belt sheave connected with gearbox input shaft as illustrated in Fig. 22.3.

The vibration data were collected by a tri-axial accelerometer installed on the top of the gearbox. The accelerometer is also shown in Fig. 22.3. The frequency limit is set to 5 KHz in the data acquisition. During the test, the motor speed was kept at 1000 RPM and the brake loader was set to 2.5. First, the baseline gearbox vibration data are collected. Then, the gearbox is disassembled, and the pinion gear is taken out. The surface of a pinion tooth on the meshing side is milled with a drill mill. After the damage is done, the pinion gear is put back into the gearbox. Vibration data are collected again with all the other running conditions kept the same (speed and load). The data were processed using traditional RMP averaging and time synchronous averaging.

Fig. 22.1 Machinery fault simulator and gearbox in MFS



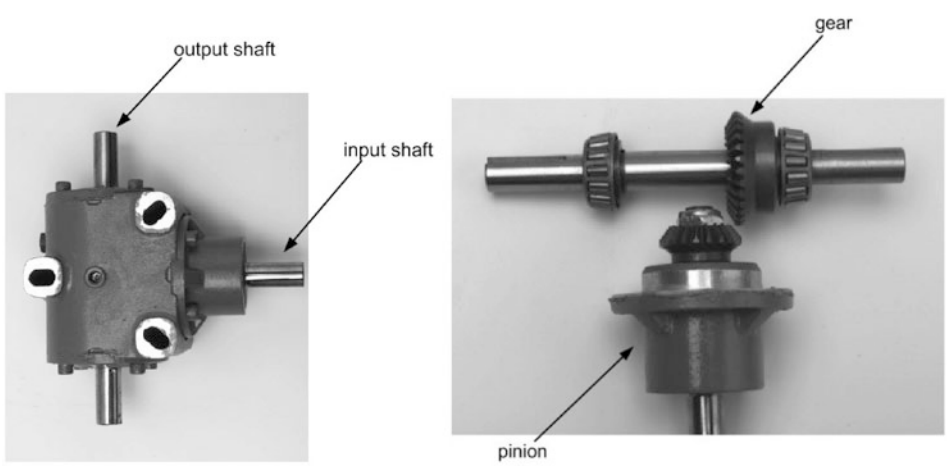


Fig. 22.2 Gearbox. (**a**) Gearbox. (**b**) Pinion and gear

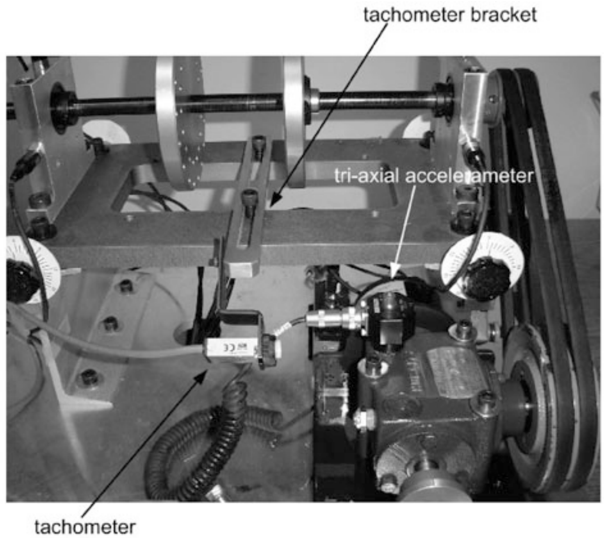


Fig. 22.3 Installation of tachometer on the gearbox

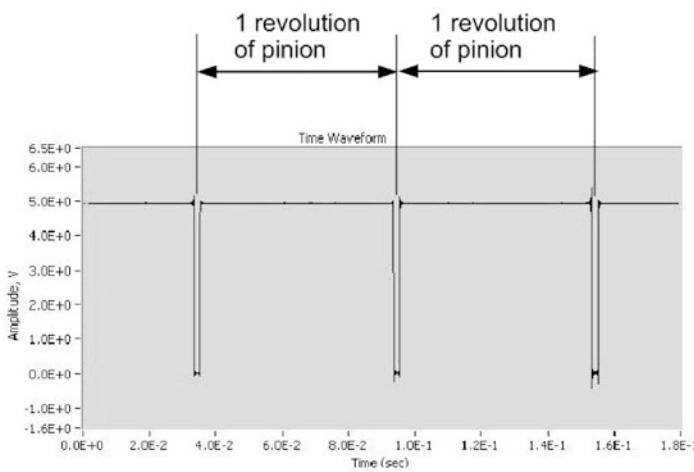


Fig. 22.4 Baseline signals in time domain

22.3 Test Results

22.3.1 Time Domain

The baseline waveforms illustrated in Fig. 22.4a, b are the tachometer signal and gearbox acceleration in the axial direction, respectively. The time between two successive pulses in the tachometer signal is the rotation period of the pinion. The time scales on these two figures show the identical time range.

The waveform for damaged pinion is illustrated in Fig. 22.5. Comparing of Fig. 22.5 with Fig. 22.4b, it can be noticed that there are impulses appearing in Fig. 22.5.

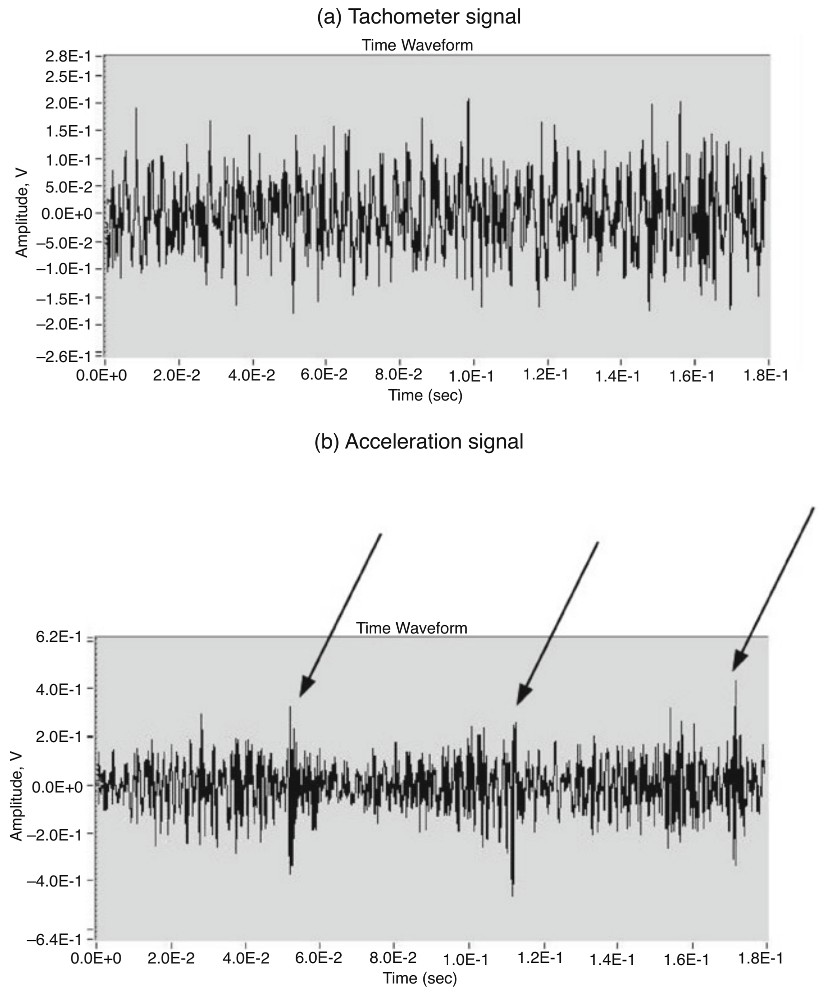


Fig. 22.5 Time acceleration signal Signals of damage pinion. (**a**) Tachometer signal. (**b**) Acceleration signal

22.3.2 Frequency Domain

The spectrum of the baseline vibration data is illustrated in Fig. 22.6. Figure 22.6a is the spectrum in the baseband spectrum, and Fig. 22.6b is the spectrum around the mesh frequency with frequency range from 250 to 350 Hz (the mesh frequency is around 300 Hz, 1000 RPM/60*18 = 300 Hz). The mesh frequency and its harmonics are illustrated clearly in Fig. 22.6b. Figure 22.6b reveals that there is pinion rotation modulation sideband around mesh frequency component. However, the sideband is not dominant [2].

The spectrum for worn gearbox with RMS spectral average is shown in Fig. 22.7 and that with time synchronous averaging about motor tachometer is illustrated in Fig. 22.8. The spectrum data in Fig. 22.7 are caused by random vibration due to gears and bearing looseness and wear resulting in raised floor. The spectrum in Fig. 22.8 is time synchronously averaged about the gearbox tachometer. This operation brings mean down and enhances spectral peaks associated the Gearmesh frequency and side bands [4, 5]. Figure 22.9 shows time synchronously averaged about the motor shaft tachometer [2]. Since belt drive ration is non-integer multiple of the input shaft, the spectra associated with gearbox is averaged out when time synchronous averaging performed about the motor shaft.

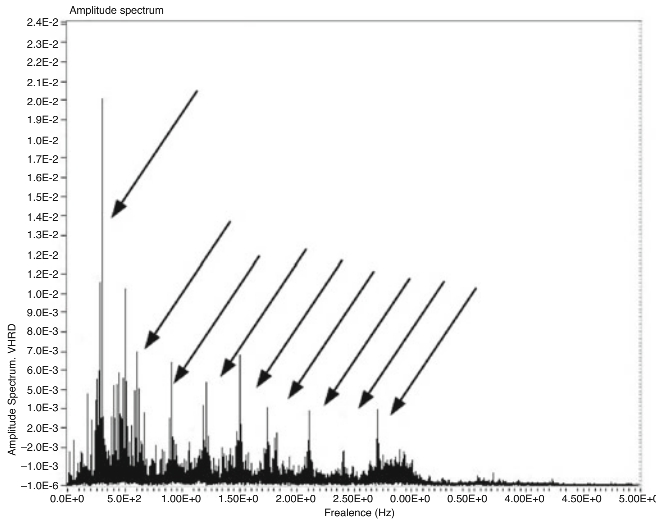
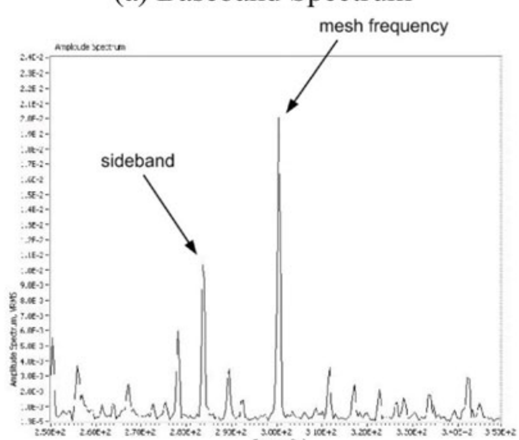


Fig. 22.6 Baseline vibration signal spectrum

(a) Baseband Spectrum



(b) Spectrum around Mesh Frequency Component

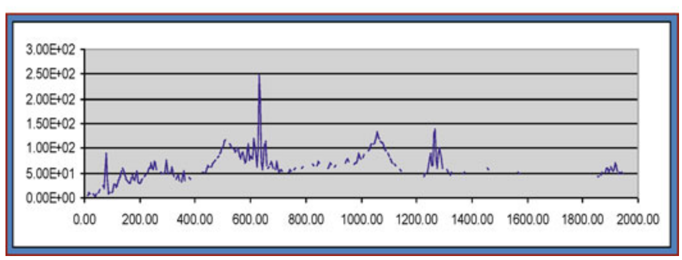


Fig. 22.7 Vibration signal spectrum of a worn gearbox with RMS spectral averaging. (**a**) Baseband spectrum. (**b**) Spectrum around mesh frequency component

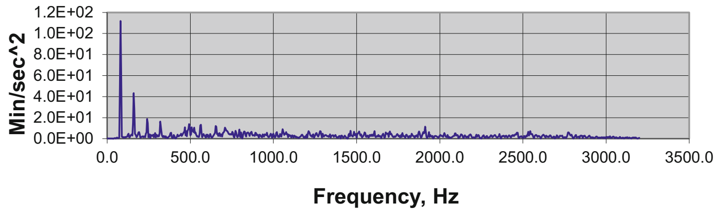


Fig. 22.8 Vibration signal spectrum of a worn gearbox with time synchronous averaging about the motor shaft tachometer

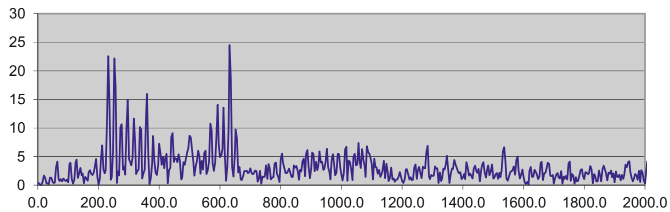


Fig. 22.9 Vibration signal spectrum of a worn gearbox with time synchronous averaging about the gearbox tachometer

22.4 Summary and Remarks

In this test, vibration signature caused by bevel gear tooth seeded fault is studied in the time and frequency domains. The pinion gear in the gearbox is intentionally faulted with increasing severities and vibration signal is collected for each case. The signal is analyzed in time and frequency domain. Frequency domain was analyzed using conventional RMS and time synchronous averaging about motor shaft and the gearbox shaft, respectively. Time synchronous averaging clearly shows Gearmesh frequency and gear/pinion-associated side bands. The results clearly illustrate the advantage of using two tachometers for in-depth analysis of gear damage. When a faulted bevel gear tooth enters meshing, it creates an impact pulse in the time domain vibration signal. The amplitude of impulse increases with damage.

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