Fault diagnosis of Spur gear using vibration analysis

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Abstract: Fault detection in gear train system is important in order to transmitting power effectively. Vibration signals extracted from rotating parts of machineries carries lot many information within them about the condition of the operating machine. Further processing of these raw vibration signatures measured at a convenient location of the machine unravels the condition of the component or assembly under study. In this paper we study the faults that occur in the spur gear and compare fault signs of them in the time and frequency domain signals.
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1-Introduction

Gears are critical elements in complex machinery, so predictive maintenance is often applied to them. Signal analysis has been an important and indispensable part of fault diagnosis. Vibration analysis has successfully been applied towards monitoring and diagnosis in many practical areas for three decades. In the application of machine fault diagnosis, vibration signal analysis is used to detect the dynamic characteristics of machines and to extract fault characteristics if a fault occurs and then identify its cause [1,2].

While a local defect such as crack occurred on gear tooth, a short duration impulsive signal will be generated. The impact will produce additional amplitude and phase modulation effects to the gear meshing components. As a consequence, a few of sidebands of the tooth-meshing frequency and its harmonics will spread over a wide range frequency. It is difficult to detect the spacing and evolution of sideband families in the frequency spectrum due to noise and vibration from other mechanical components [3,4,5].

Diagnosing a gear system by examining vibration signals is the most commonly used method for detecting gear failures. The conventional methods for processing measured data contain the frequency domain technique, time-domain technique ,and time-frequency domain technique. These methods have been widely employed to detect gear failures. The use of vibration analysis for gear fault diagnosis and monitoring has been widely investigated and its application in industry is well established [6,7,8].

This is particularly reflected in the aviation industry where the helicopter engine, drive trains and rotor systems are fitted with vibration sensors for component health monitoring. These methods have traditionally been applied, separately in time and frequency domains. A time-domain analysis focuses principally on statistical characteristics of vibration signal such as peak level, standard deviation, skewness, kurtosis, and crest factor. A frequency domain approach uses Fourier methods to transform. the time-domain signal to the frequency domain, where further analysis is carried out, and conventionally using vibration amplitude and power spectra. It should be noted that use of either domain implicitly excludes the direct use of information present in the other. Time-frequency based energy distribution method was employed for early detection of gear failure [4]. The frequency domain refers to a display or analysis of the vibration data as a function of frequency. The time-domain vibration signal is typically processed into the frequency domain by applying a Fourier transform, usually in the form of a fast Fourier transform (FFT) algorithm[9, 10 ,11].

In this paper we investigate the faults which occur in gears and compare the signs of these faults .so, we present the time and frequency signals of these faults.

2-Gear defects

A gearbox is a piece of rotating equipment that can cause the normal low frequency harmonics in the vibration spectrum, but also show a lot of activity in the high frequency region due to gear teeth and bearing impacts. The spectrum of any gearbox shows the 1. and 2. rpm, along with the gear mesh frequency (GMF). The GMF is calculated by the product of the number of teeth of a pinion or a gear, and its respective running speed:

GMF = number of teeth on pinion ×pinion rpm

The GMF will have running speed sidebands relative to the shaft speed to which the gear is attached. Gearbox spectrums contain a range of frequencies due to the different GMFs and their harmonics. All peaks have low amplitudes and no natural gear frequencies are excited if the gearbox is still in a good condition. Sidebands around the GMF and its harmonics are quite common. These contain information about gearbox faults (Fig 1).

Tooth wear and backlash can excite gear natural frequencies along with the gear mesh frequencies and their sidebands. Signal enhancement analysis enables the collection of vibrations from a single shaft inside a gearbox.

Cepstrum analysis is an excellent tool for analyzing the power in each sideband family. The use of cepstrum analysis in conjunction with order analysis and time domain averaging can eliminate the 'smearing' of the many frequency components due to small speed variations (Fig 2).

As a general rule, distributed faults such as eccentricity and gear misalignment will produce sidebands and harmonics that have high amplitude close to the tooth-mesh frequency. Localized faults such as a cracked tooth produce sidebands that are spread more widely across the spectrum[12].

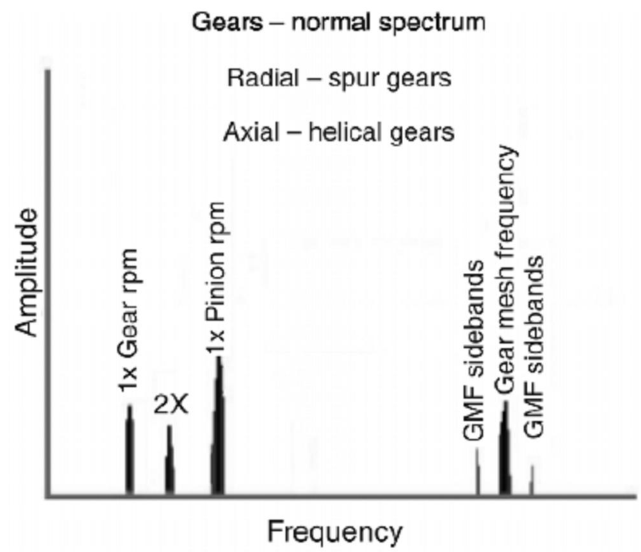

Fig 1-Graph of a gearbox spectrum

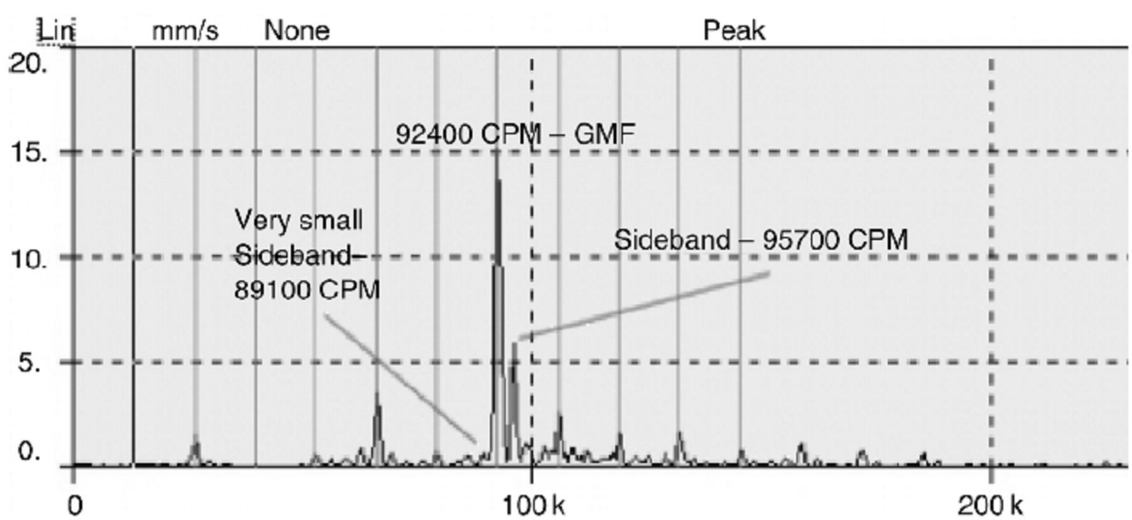

Fig 2-FFT spectrum from a noisy gearbox with pinion having 28 teeth and rotating at 3300 rpm

3-Gear tooth wear

An important characteristic of gear tooth wear is that gear natural frequencies are excited with sidebands around them. These are spaced with the running speed of the bad gear .The GMF may or may not change in amplitude, although high-amplitude sidebands surrounding the GMF usually occur when wear is present. Sidebands are a better wear indicator than the GMF itself (Fig 3)[12].

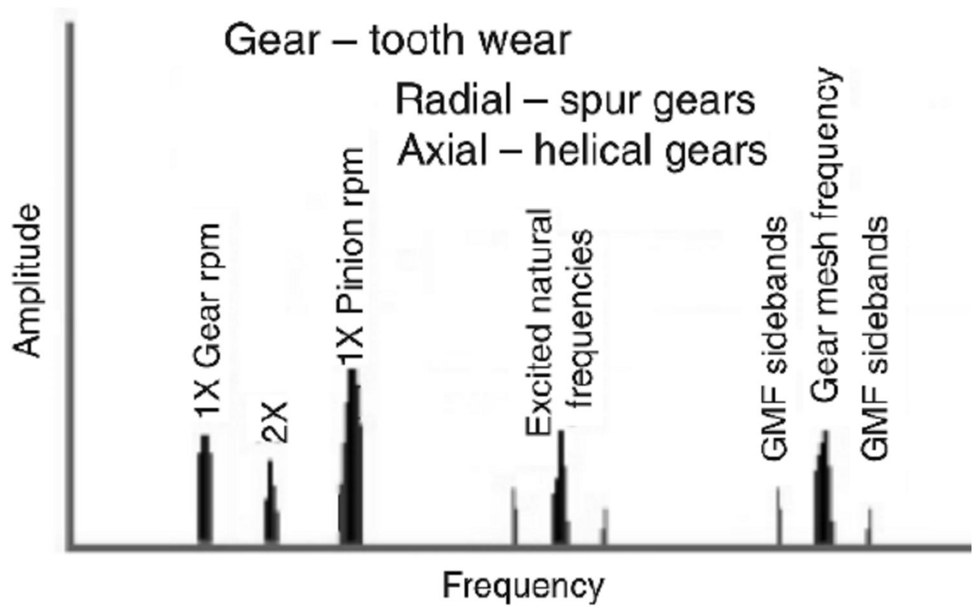

Fig 3-Gear tooth wear

4-Gear tooth load

As the load on a gearbox increases, the GMF amplitude may also increase. High GMF amplitudes do not necessarily indicate a problem, particularly if sideband frequencies remain low and no gear natural frequencies are excited. It is advised that vibration analysis on a gearbox be conducted when the gearbox is transmitting maximum power (Fig 4).

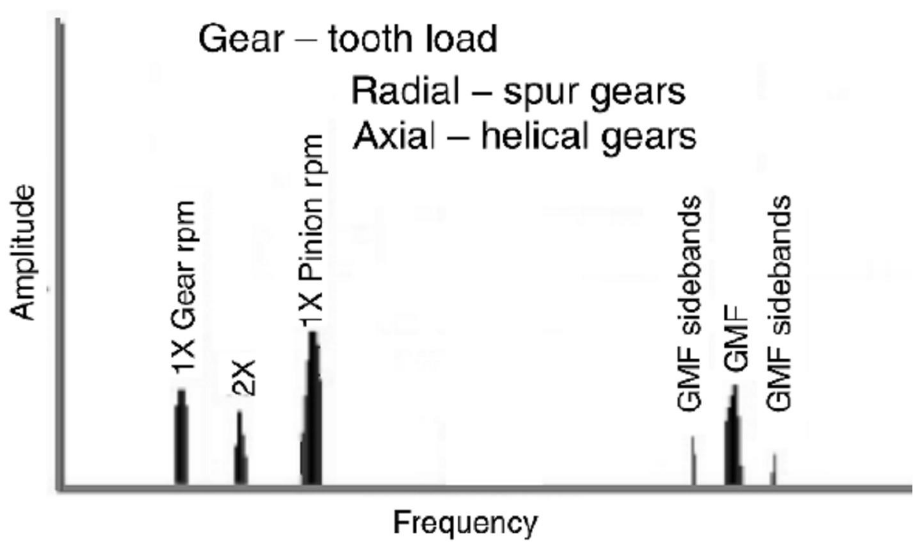

Fig 4- Gear tooth load

5-Gear eccentricity and backlash

Fairly high amplitude sidebands around the GMF often suggest gear eccentricity, backlash or non-parallel shafts. In these cases, the rotation of one gear may cause the amplitude of gear vibration to modulate at the running speed of the other. This can be seen in the time domain waveform. The spacing of the sideband frequencies indicates the gear with the problem. Improper backlash normally excites the GMF and gear natural frequencies. Both will have sidebands at 1Xrpm. The GMF amplitudes will often decrease with increasing load if backlash is the problem (Fig 5)[12].

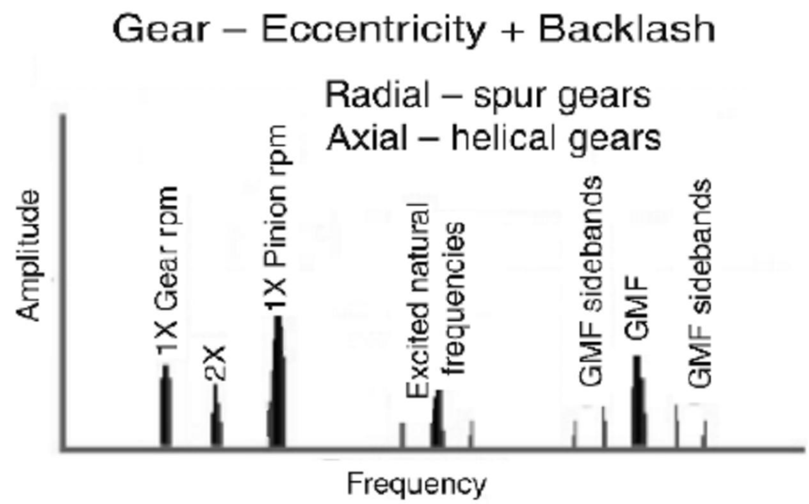

Fig 5-Gear eccentricity and backlash

6-Gear misalignment

Gear misalignment almost always excites second order or higher GMF harmonics, which will have sidebands spaced with the running speed. It will often show only small amplitudes at 1X GMF, but much higher levels at 2X or 3X GMF. It is important to set the F-max of the FFT spectrum to more than 3X GMF (Fig 6).

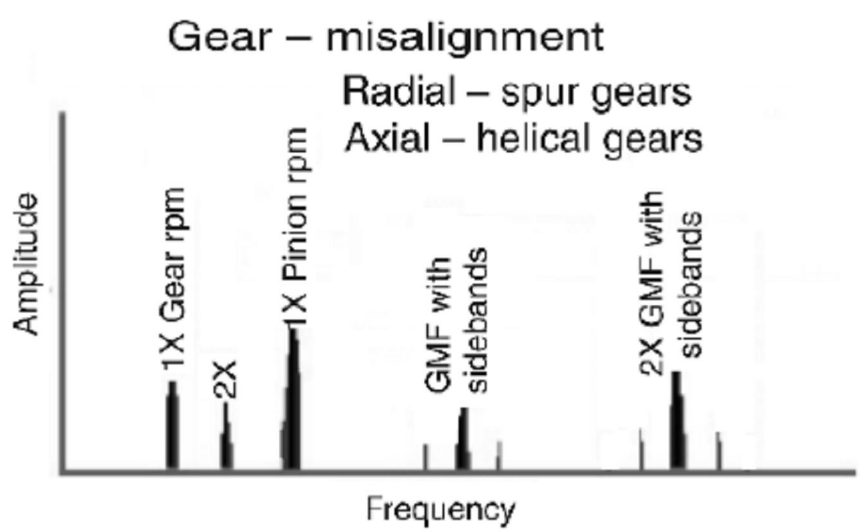

Fig 6-Gear misalignment

7-Gears – cracked or broken tooth

A cracked or broken gear tooth will generate high amplitude at 1X rpm of this gear, plus it will excite the gear natural frequency with sidebands spaced with its running speed. It is best detected in the time domain, which will show a pronounced spike every time the problematic tooth tries to mesh with teeth on the mating gear. The time between impacts will correspond to 1Xspeed of the gear with the broken tooth .The amplitude the impact spike in the time waveform will often be much higher than that of the 1X gear rpm in the FFT spectrum (Fig 7)[12].

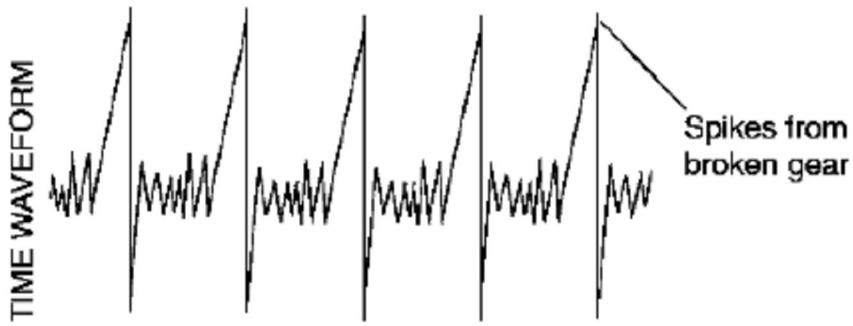

Fig 7- Gears – cracked

8-Gears – hunting tooth problems

The gear hunting tooth frequency is particularly effective for detecting faults on both the gear and the pinion that might have occurred during the manufacturing process or due to mishandling. It can cause quite high vibrations, but since it occurs at low frequencies, predominantly less than 600 cpm, it is often missed during vibration analysis. The hunting tooth frequency is calculated with:

$$\text{Hunting Tooth Frequency} = (GMF \times N) / ((\text{no. of pinion teeth}) \times (\text{no. of gear teeth}))$$

In the above equation, N is known as the assembly phase factor, also referred to as the lowest common integer multiple between the number of teeth on the pinion and gear. This hunting tooth frequency is usually very low.

If the tooth repeat frequency is a problem (Fig 8), one can usually audibly hear it since it is a beat frequency. A gear set with a tooth repeat problem normally emits a 'growling' sound from the driven end. Its repetition rate can often be established by simply counting the sounds using a stopwatch. The maximum effect occurs when the faulty pinion and gear teeth mesh at the same time (on some drives, this may occur once every 10 or 20 revolutions, depending on the Fht formula).

Gearboxes can generate crowded and complex FFT spectrums with many unusual and unidentifiable frequencies. Another unusual frequency encountered in the gearbox is a sub-multiple of the gear mesh frequency. This vibration is generally the result of an eccentric gear shaft misalignment or possibly a bent shaft. Any one of these cases can cause variations in the tooth clearances for each revolution of the gear. As a result, the amplitude of the gear mesh frequency may appear modulated as shown in Fig 9[12]. Gear tooth impacts may only be excessive during portions of each revolution of the gear. Therefore the resulting vibration will have a frequency less than the gear mesh frequency. However, it will remain a multiple of the gear rpm.

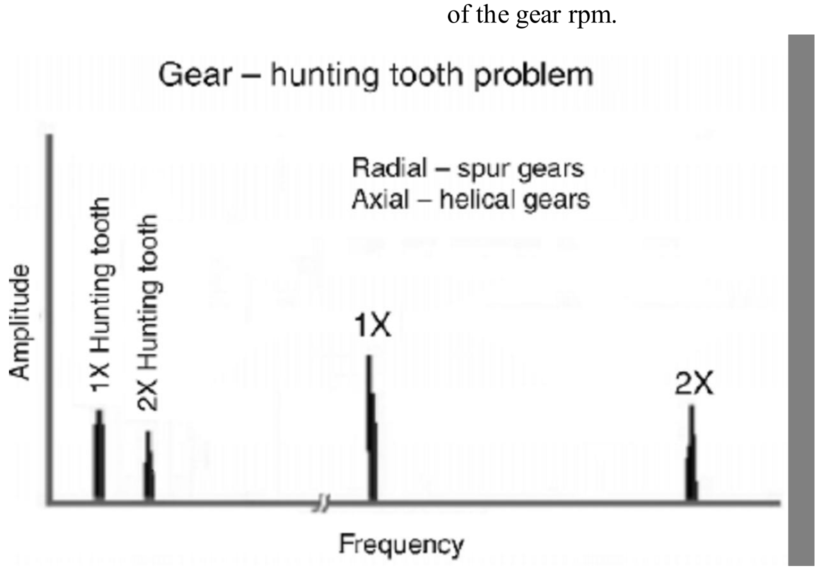

Fig 8-Gear – hunting tooth problem

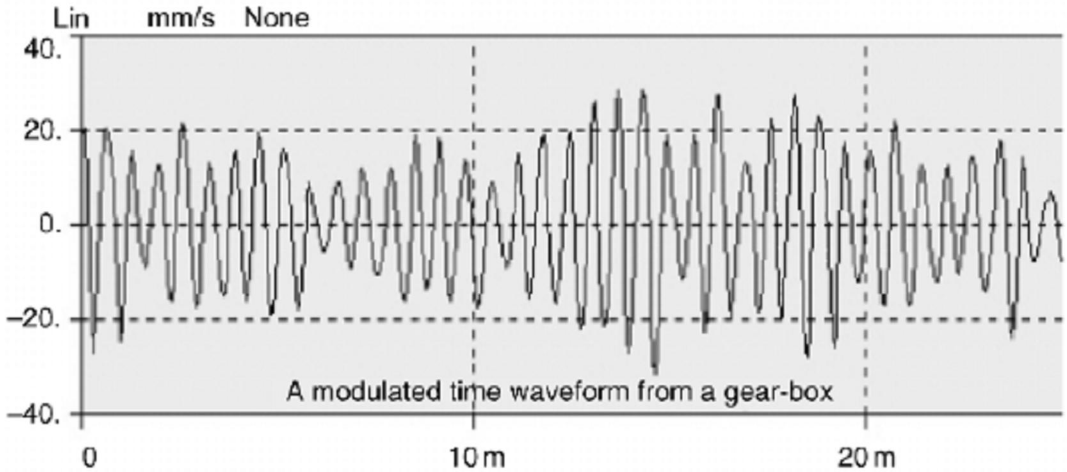

Fig 9-Modulated amplitude from a gearbox with a GMF of 92400 cpm

9- Conclusion

Fault diagnosis of Gear box is one of the core research areas in the field of condition monitoring of rotating machines .This work has investigated various signals of gear faults. Results showed that , there are differences between fault signals of gears in both time domain and frequency domain that happened in each defect of gears. So we can compare these signals and find the fault of gear.

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