Research Paper Engineering

Fault Diagnosis of Gear Box by Analysis of Power Density Spectrum of Vibration Signals using Hilbert Transform

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ABSTRACT

This work provides fault diagnosis of a gearbox by Analysis of Power Density Spectrum of Vibration Signals using Hilbert transform.The objective of this study is to investigate the correlation between vibration analysis and fault diagnosis in a gearbox.This was achieved by vibration analysis and investigating different operating conditions of a Single stage spur gearbox.For this purpose the gearbox is coupled to the a motorand the observations were taken at three different levels of speed 780 rpm, 1080 rpm and 1200 rpm.Vibrations of the gearbox are converted into voltage signal (milivolt) using an accelerometer/piezoelectric transducer.The gears are taken in two different conditions viz Healthy (normal gear) and Faulty (broken-teeth gear) with the aim of fault detection.Vibration data of the healthy gearbox are used as a standard for the analysis of the vibration spectra of faulty gearbox .Demodulation is an important issue in gearbox fault detection,as the vibration signatures of the faulty gear contains both gear meshing frequency as well as the the faulty frequency.These signals are then analyzed through different operations performed in MATLAB software.The result shows that Power Density Spectrum of Vibration Signals using Hilbert Transform method provides efficient representation of fault detection in gear.

Keywords: Vibration signatures , Demodulation , Carrier signal , Fault diagnosis

1.Introduction

In condition monitoring and fault diagnosis of machinery and equipment, especially in rotating machinery and reciprocating machinery, the vibration diagnosis is one of important methods. Gears are very important components in the field of mechanical engineering .Due to their vast utilization in drive systems, gears are the object of interest of many researchers working in the field of diagnostic machinery. Many techniques are devised to create appropriate tools to upgrade the fault identification process especially in their early phase .Identification of the fault in its early stage prevents the damage of the machine and loss of money. Generally, a gear undergoes faults like chipping, pitting and crack etc.This paper is an attempt to investigate the correlation between vibration analysis and fault diagnosis in a gearbox. When a pair of gears is running in healthy condition then it generates a vibration signature having a specific amplitude , phase ,frequency this wave is known as the Carrier wave & the frequency of this wave is the centre frequency called the carrier frequency.When a gear has a local fault (a fault which is located at a particular point on a gear) , then the vibration signal of the gearbox gets modulated. The modulation occurred in the vibration signatures may be amplitude modulation or frequency modulation that are periodic with the rotation frequency of the gear.The modulation of the meshing frequency, as a result of faulty teeth, produces sidebands, which are frequency components equally spaced around a centre frequency. The important components in gear vibration signatures are the meshing frequency of the gear tooth and their harmonics along with the side bands (expected faulty frequency).

Amplitude modulations are present when a gear meshes an eccentric gear or a gear running on a bent or shaft.Due to the local gear fault, the gear angular velocity could change as a function of the rotation.As a result of the speed variation, frequency modulations occur.In many cases,both amplitude and frequency modulations may present. Due to which the generation of sidebands takes place & the increasing in the number and the amplitude of such sidebands often indicates a rise in the faulty conditions. Since modulating frequencies are caused by certain faults of machine components,thus the detection of the modulating signal is very useful to detect gearbox fault.This paper proposes a technique for the fault detection which uses the analysis of vibration signals generated by pair of gears.This method is an very effective for the detection fault in the rotating machine component in its early stage.

2. Description of the Experimental Setup used –

Table 1 : Specification of the Experimental SetUp (Single Stage Spur gear Transmission)

S.No.	Component	Dimensions (mm)
1.	Diameter of driver (D)	58
2.	Diameter of driven (d)	66
3.	Center distance between shafts (O_1O_2)	62
4.	No. of teeth on driver (T)	32
5.	No. of teeth on driven (t)	35
6.	Gear type	Spur
7.	Gear ratio (G)	0.91
8.	Bearing	Roller
9.	Bearing dia.inner	18.5
10.	Bearing dia.outer	52
11.	Fault Created	Half tooth cut
12.	Provision for mounting gears on shaft	Keyway
13.	Loading Condition	Rope Brake Dynamometer
14.	Heavy Wooden basement with rubber dampers	Better Stability and Machinability
15.	Motor	2.1A/230V/1500rpm

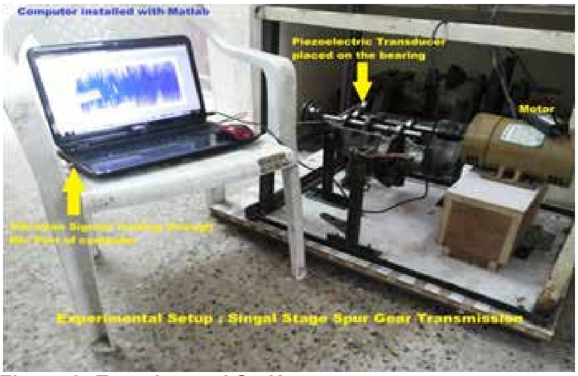

Figure 2: Experimental SetUp

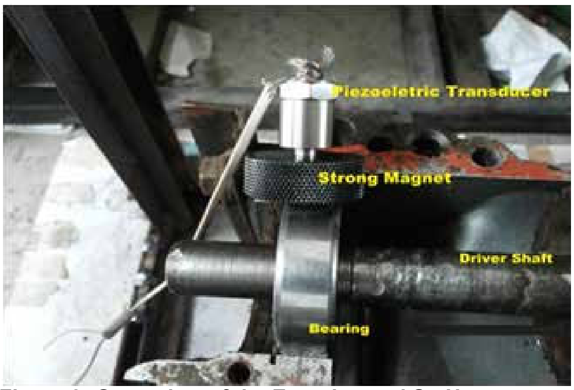

Figure 3: Open view of the Experimental SetUp

3. Analysis of gear vibration signals collected -

First of all the healthy gear (4 mm total depth and 16 mm tooth thickness) & faulty gears (half portion of the tooth is chipped out , chip size is 1.5 mm deep and 4 mm long) are mounted on the driver shaft one by one for this purpose the shafts and gears are provided by keyways.The vibration signals of the gears are collected at constant speed of 780 rpm.An accelerometer is used for this purpose which is placed close to the roller bearings supporting the shaft whose gears are to be tested.The location of the device is very significant while loading the vibration signals.This procedure is repeated at two different speed levels viz 80% & 50% of the maximum speed of the motor which is 1500 rpm and the results are concluded.The speed of the shaft is measured by using an digital tachometer.

Observation	Motor Speed (rpm)	Motor Speed (%)	Vibration Signals
1.	1200	80	Collected by Piezoelectric
2.	750	50	Collected by Piezoelectric

Table 2 :Readings taken at different speeds of motor

Figure 1:Shows the Healthy & the Faulty Gear used

One end of the sensitive cable is attached to the accelerometer/piezoelectric (element) transducer while the other end to the Micport of the computer and the vibration signals of the gearbox are loaded in the computer through Matlab Software. The vibration signals collected are in time-domain form.The vibration signatures of the healthy pair of gears are taken as standard which are assumed to be free from any type of modulations.These signals are known as carrier signal since, it has a high frequency generally this frequency corresponds to the meshing of the tooth of the gears known as tooth-meshing frequency.

The vibration signatures of both the healthy & the faulty gear obtained in time domain are:

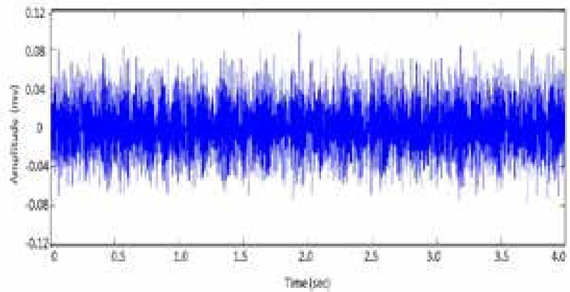

Figure 4: Vibration Signature of the Healthy Gear in Time Domain.

When a faulty gear is introduced, the vibration signal of the gearbox contains modulations. There may be amplitude and phase modulations that are periodic with the rotation frequency of the gear. The modulation of the meshing frequency generates some other frequencies spreaded in a particular range/space around the carrier signal known as sidebands.

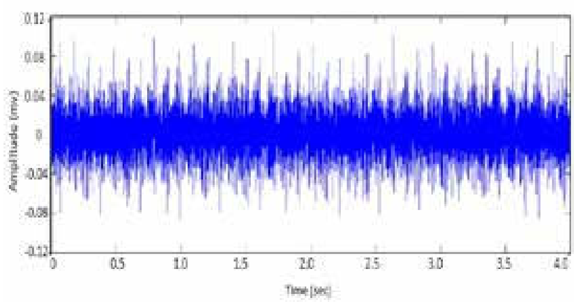

Figure 5:Vibration Signature of the Faulty Gear in Time Domain.

As it is very difficult to compare figure 4 & 5 in time domain therefore this signal is converted in frequency domain.

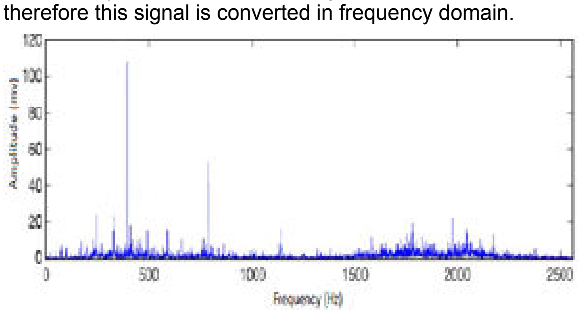

Figure 6: Vibration Signature of the Healthy Gear in Frequency Domain

Figure 6 shows the power density spectrums of signals in Figure 4 and 5. Gearbox speeds have some fluctuations in this experiment. Many low frequency bands appears around the meshing frequency, approximately 400 Hz, and its harmonics exist in Figure 6 and 7.The comparsion of the frequency of

Healthy gear in Figure 6 and faulty gear in Figure 7 cannot offer the exact fault signatures however, it is quiet obvious after the analysis of the power density spectrum of signals that there is an increase in the number of sidebands which reflects the faulty conditions and this faults are expected to be located somewhere near 13 Hz .

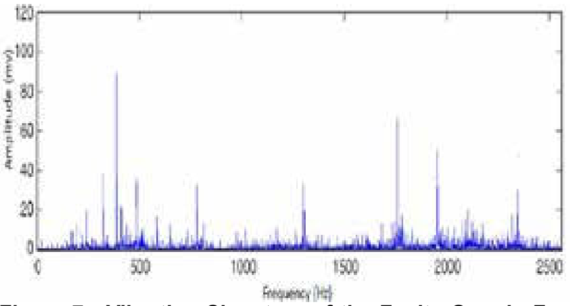

Figure 7 : Vibration Signature of the Faulty Gear in Frequency Domain.

Figure 8 and 9 shows the power density spectrums of vibration signals' envelopes. In order to visualize the whole spectrum , we have taken a range from 0 to 240 Hz by means of scaling in the software.(The zooming of the figure will not effect the fault detection results since the faulty frequencies are generally located in the low frequency region).On observing frequencies 11 Hz, 13.85 Hz, 19 Hz, and 24 Hz in the frequency domain in Figure 8. and the frequency 13.85 Hz (expected faulty frequency 13 Hz) in both the figures 8 and 9.

(i) The amplitude of 13.85 Hz frequency in Figure 9 (Faulty gear) is nearly 25 mV which is much higher than the amplitude 14 mV at the same frequency 13.85 Hz in Figure 8 (healthy gear) .

and (ii) There is very slight difference in the amplitudes of other frequency components of 11 and 19 and 24 Hz Figure 8 and 9.Thus, it is clear from points (i) and (ii) that the 13.85 Hz frequency is the faulty frequency.

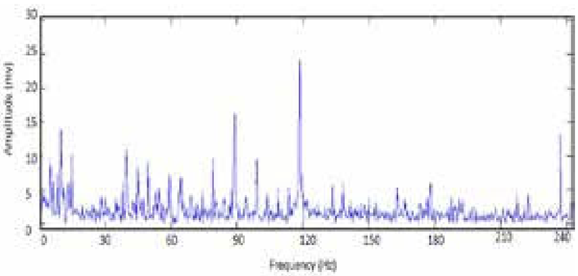

Figure 8 :Power density spectrum of envelope signals of the Healthy gear

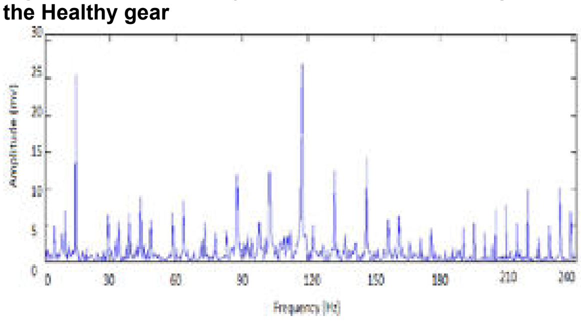

Figure 9 :Power density spectrum of envelope signals of the faulty gear

4. Application of Hilbert transform -

The Hilbert transform is useful in calculating instantaneous attributes of a time series,especially the amplitude and frequency. The Hilbert transform facilitates the formation of the analytic signal.The hilbert function computes the Hilbert transform for a real input signal (x) and generates a complex result of the same length as y = hilbert(x) as output , where the real part of y is the original real data and the imaginary part is the actual Hilbert transform.y is known as the analytic signal, in reference to the continuous-time analytic signal.

Hilbert transform is a time-domain convolution that maps one real-valued time-history into another. It is defined by

$$H[x(t)] = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{x(t)}{t-\tau}\, d\tau \quad \text{.......................(i)}$$

where t is time, x(t) is a time domain signal and H[x(t)] is the Hilbert transform of x(t).Because Hilbert transform is a frequency-independent 90° phase shifter, the non-stationary characteristics of the modulating signal are not affected by this method at all.Modulation functions, a x(t) and b x(t) respectively can be extracted by Hilbert transform.

$$A[x(t)] = x(t) + iH[x(t)] = a(t)e^{i\phi(t)} \quad \text{.........(ii)}$$

The resulting complex time-domain signal may be transformed from the real/imaginary form to the magnitude phase form by

$$a(t) = \sqrt{x^2(t) + H^2[x(t)]} \quad \text{......................(iii)}$$

Finally the Hilbert transform removes carrier signals (tooth meshing frequencies) and this will decrease the effect of immaterial information for the purpose of gearbox fault detection & the extracted modulated signal may be analysed as the modulated signal (low frequency) is the fault containing signal.

5. Results and discussion -

The experimental setup consists of two shafts driver and follower.The healty and the faulty gear are mounted one by one on the driver shaft which is revolving at 780 rpm i.e at 13 rps = 13 Hz , therefore 13 Hz frequency is our expected faulty frequency also the meshing frequency of gear 1 and gear 2 is (13Hz*32 teeth) **=** 416 Hz.After the analysis of the power density spectrums of vibration signals' envelopes in Figure 8 and 9. On observing frequencies 11 Hz, 13.85 Hz, 19 Hz, and 24 Hz in the frequency domain in Figure 8. and the frequency 13.85 Hz (expected faulty frequency 13 Hz) in both the figures 8 and 9.

(i) The amplitude of 13.85 Hz frequency in Figure 9 (Faulty gear)is nearly 25 mV which is much higher than the amplitude 14 mV at the same frequency 13.85 Hz in Figure 8 (healthy gear) .

and (ii) There is very slight difference in the amplitudes of other frequency components of 11 and 19 and 24 Hz Figure 8 and 9.Thus, it is clear from points (i) and (ii) that the 13.85 Hz frequency is the faulty frequency.

6.Conclusion –

From the results we have concluded that only the amplitude of 13.85 Hz frequency has a significant difference from 14 mV to 25 mV in the final power spectrum signals and this 13.85 frequency is very close to the expected faulty frequency of 13 Hz.Thus,the results for the actual gearbox vibration signals shows the effectiveness of the method to extract the faulty signals buried in the noisy vibrations.This paper shows the importance of the co-relation between the vibration signatures of the machine component and machine's present condition.Also,the significance of vibration analysis in the field of condition monitoring is revealed.Any type of emerging fault in the gear box can be diagnosed in its early stage and its root cause may be sorted in a minimum time without hampering the running condition of a particular machine/set up.These fault diagnosis methods may play a vital role in industries where continous manufacturing is an important concern.

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