IDENTIFICATION OF PITTING DEFECT IN A GEARBOX HAVING 20MnCr5 GEAR THROUGH VIBRATION ANALYSIS

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Abstract - *The main aim of this study is to conduct vibration analysis of the gearbox test rig with healthy and defective gears (gear with Pitting tooth defect), which may be effective in pre-emptive system failure detection. Primarily, in the gearbox test rig, Healthy gears were mounted and run under different speeds and different loads and signals were sensed using accelerometer and captured using data acquisition systems (DAQ) to recognize the standard behavior of normal gears. The Healthy gears were then substituted with defective gears, and signals were recorded separately in the same condition for each of the case. After that, four proposed vibration measurement techniques, namely: Time domain analysis, Frequency Response Function (FRF), Fast Fourier Transform (FFT), and Angular Domain Analysis are used to determine gearbox defects. It was observed from the experimental results that the vibration signals play a significant role in the assessment of the gearbox defects. Finally, it was found that the gearbox's vibration amplitudes were increased, resulting in increased Pitting tooth defect in the gear under different speeds and loads.*

***Key Words*: Gearbox, Time Domain Analysis, Frequency Response Function (FRF), Fast Fourier Transform (FFT).**

1. INTRODUCTION

Gearbox is necessary for prime movers to transmit the power from one part to another. Gearbox contains many parts such as gear pairs, bearings, shafts, coupling etc., and each part has its own vibration characteristics due to reasons such as the shaft misalignment because of over load or bent shaft, the coupling looseness because of loosened fasteners, defects in inner race, outer race, rollers and cage of bearings, misalignment due to improper mounting of gear and looseness due to backlash effect. Hence health condition monitoring of gearbox is very essential for ensuring designed performance levels of the mechanical systems [1].

Pitting is a surface fatigue failure of the gear tooth. It occurs because of repeated loading of tooth surface and the contact stress exceeds the surface fatigue strength of the material. Material in the fatigue region gets removed and a pit is formed. The pit itself will cause stress concentration and soon the pitting spreads to adjacent region till the whole surface is covered. Subsequently, higher impact load resulting from pitting may cause fracture of already weakened tooth. However, the failure process takes place over millions of cycles of running [3].

Gear teeth in a power transmitting gearbox are subjected to fatigue loading. Minute defect in the gear material like micro voids or machining marks at the roots of the gear teeth can lead to creation of micro cracks, when subjected to fatigue loading. With continuous loading, these micro cracks can coalesce and form a macro crack, which can grow with further loading causing tooth breakage. Once a tooth breaks in a gear train, it can lead to higher impact force causing breaking of more number of teeth, leading to catastrophic failure of the system. Hence early detection of a single tooth failure can be helpful in the prevention of total failure of the system [2].

The vibration analysis is effective and efficient method to monitor the condition of a gearbox. The main sources of gearbox vibrations are geometric error such as selection improper gear ratio. Improper mounting of gears are other source of vibration that causes misalignment. Gearbox vibration signal contains turning frequency of gears, gear mesh frequency its harmonics and sidebands around the gear mesh frequency.

Gear Mesh Frequency = Number of teeth x Shaft speed

The diagnosis of gearbox can be done by analyzing the vibration signals which includes time domain signal, frequency domain signal, order tracking and octave band analysis of noise signal.

The severity of the vibration of the gear pair can be observed in the time signal. However, time domain signals from rotational machines are often very complex.

Frequency domain signals which are obtained by performing FFT of time domain signal provide much more information about the system under investigation.

Order tracking analysis is easier to identify gear shaft frequency, gear mesh frequency and its harmonics, along with sidebands. Because order signal converts time domain to angular domain, it does not change with variation of frequency.

Overall noise level of a gearbox gives sufficient information for gear noise analysis from octave analysis.

2. METHODOLOGY

2.1 Gearbox Test Rig

The gearbox test rig consists of two spur gear pairs one serves as test gear pair and the other as master or slave gear pair. Both the gear pairs have the teeth ratio of 45/28. The load is applied on pinion through the load coupling assembly using the loading arm. The test rig has provision for easy assembly and disassembly of test gear pairs as shown in fig-1.

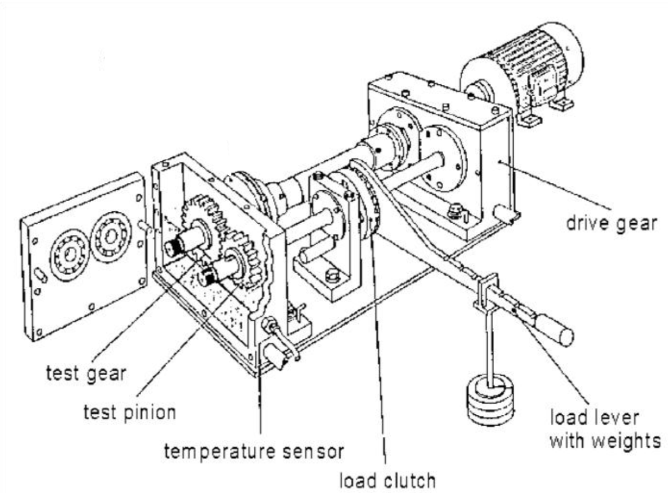

Fig -1: Schematic Representation of Gearbox Test Rig

2.2 Gear

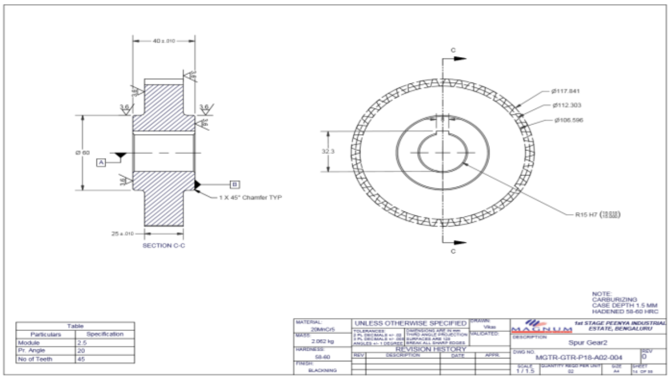

Fig -2: Gear

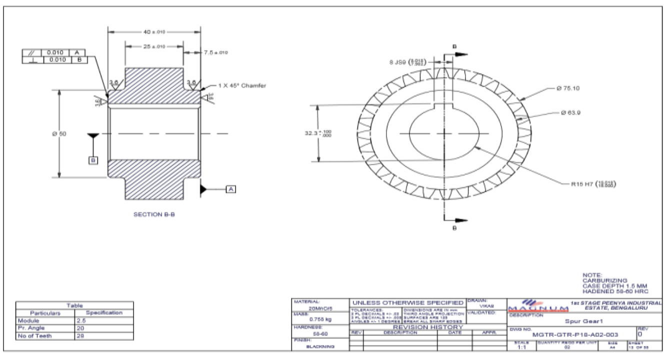

Fig -3: Pinion

Table -1: Specifications of Gear Pair

Sl. No.	Parameter	Gear	Pinion
1	Number of Teeth	45	28
2	Module (mm)	2.5	2.5
3	Pressure Angle (deg)	20	20
4	Face Width (mm)	25	25
5	Pitch Circle Diameter (mm)	112.5	70.0
6	Center Distance (mm)	91.25	91.25

a. Health Gear

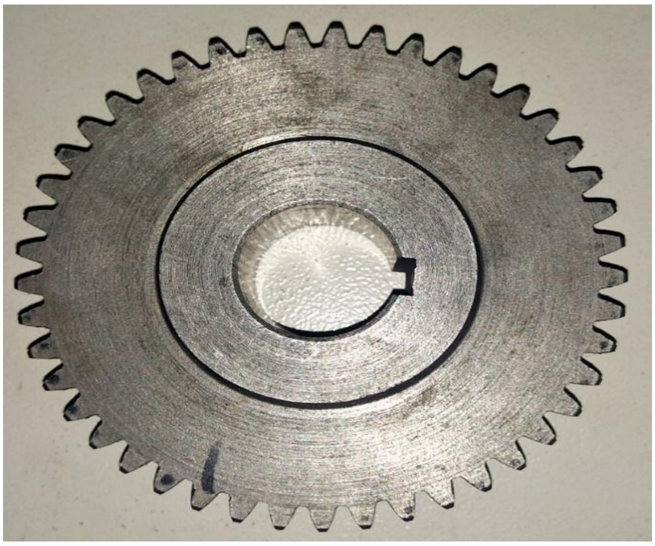

Fig -4: Healthy 20MnCr5 Gear

b. Defective Gear

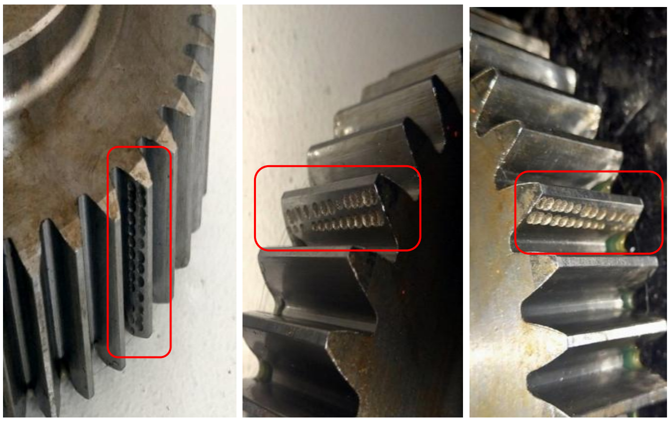

Fig -4: Defective 20MnCr5 Gear

In the present work, gear with Pitting tooth defect is included in the test gear pair, to study their effect on the vibration and noise characteristics.

2.3 Experimental setup

Gearbox test rig has been utilized to carry out the vibration analysis of gearbox in the present work.

Fig -5: Experimental Setup of Gearbox Test Rig

The experiment is carried on both healthy and defective condition of gears. Using the variable frequency drive (VFD) the operating speed is varied from 200-1000 RPM at 100 RPM increments. The accelerometer is mounted on gearbox as shown in fig-5 to sense and acquire the vibration data. To sense and acquire the sound pressure or noise level the microphone is held closer to the gear mesh region. For the corresponding measurements both the accelerometer and microphone are wired to DAQ (Data Acquisition Control). The torque is varied by changing the loads (No load, 5Kg, and 10Kg). The vibration and noise data are acquired for both healthy and faulty gears for different operating speed and torque.

3. RESULTS AND DISCUSSION

A. Frequency Response Functions (FRF)

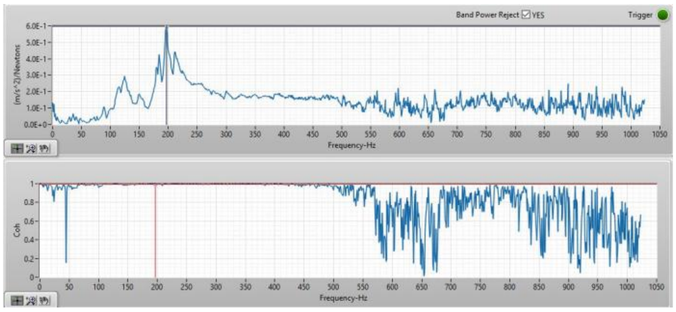

Fig -6: FRF Signal Magnitude and Coherence

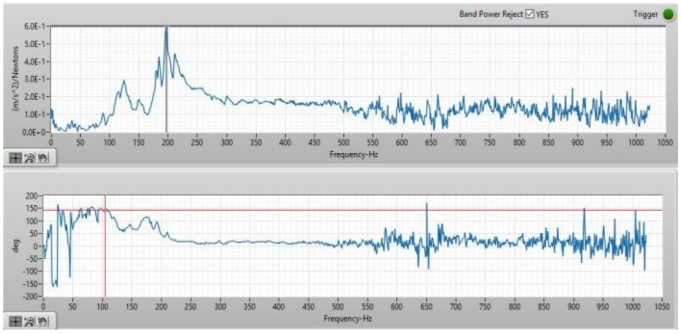

Fig -7: FRF Signal Magnitude and Phase Angle

Figure 6-7 shows FRF signal obtained from impact hammer test of the gearbox. From the FRF analysis, the Gearbox Natural Frequencies obtained are 89Hz, 124Hz, 184Hz, and 197Hz.

B. Time Domain Analysis

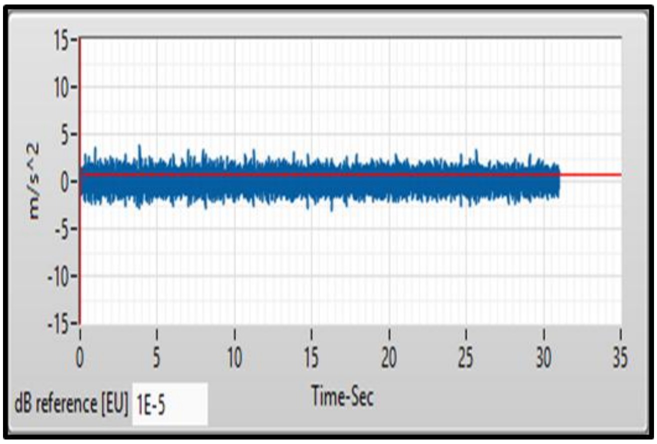

Fig -8: Time Domain Signal of Gearbox for Healthy Gear

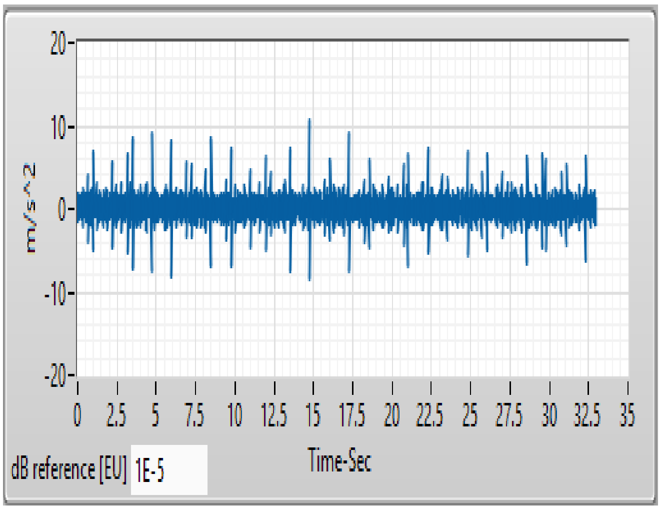

Fig -9: Time Domain Signal of Gearbox for Faulty Gear

Time domain signal indicates the severity of vibration from healthy to defective condition of gearbox. In the figure-8 there is no sudden rise in amplitude or pulse in the signal that indicates no defect or healthy condition of gear. Figure-9 shows one pulse for a revolution of shaft which indicates Pitting tooth defect in the gear train.

C. Frequency Domain Analysis

Frequency domain signals obtained after carrying out FFT of time domain signals are as shown in figure-10 and 11 for gearbox with healthy and faulty gears at 400 RPM and at No-load condition.

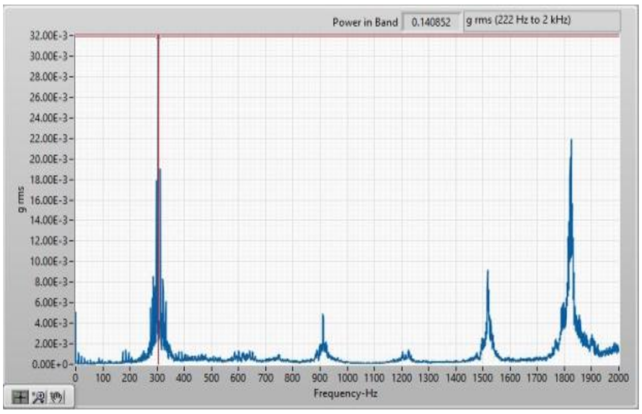

Fig -10: FFT Signal of Healthy 20MnCr5 Gear at Speed of 400RPM and No Load

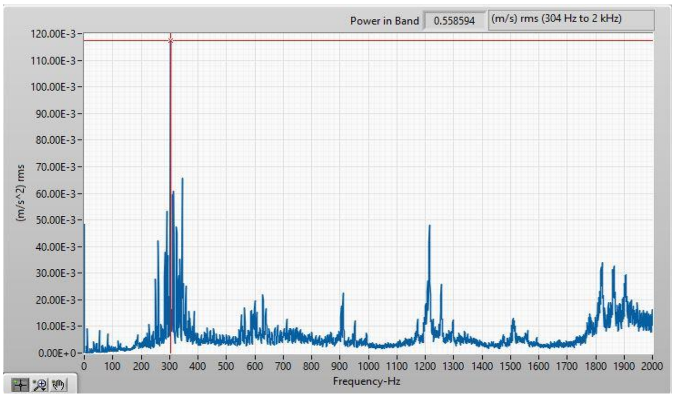

Fig -11: FFT Signal of Defective 20MnCr5 Gear at Speed of 400RPM and No Load

For the gear speed of 400RPM, the corresponding Gear Mesh Frequency (GMF) is 303Hz. Dominant peaks can be observed at GMF. The severity of vibration increasing with the number of Pitting tooth, the vibration level of healthy 20MnCr5 gear is low as shown in fig-10 when compared to other faulty 20MnCr5 gear conditions shown in fig-11.

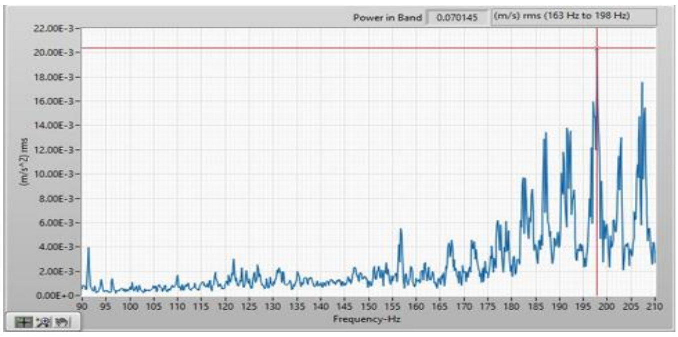

Fig -12: Zoomed FFT Showing Natural Frequency at 197Hz for Gear Running at 400 RPM with Pitting Defect

The FFT analysis shows the presence of 1x GMF and the presence of natural frequency as the symptoms of the pitting defect as shown in fig-13 and table-2.

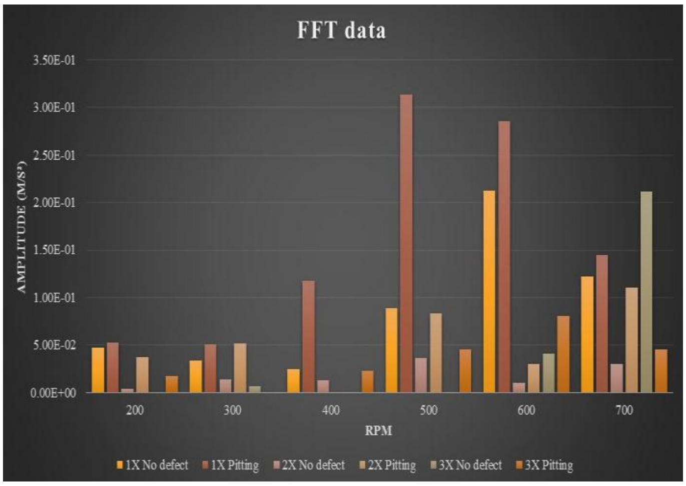

Fig -13: FFT Data for both Healthy and Defective 20MnCr5 Gear

Table -2: FFT Data for both Healthy and Defective 20MnCr5 Gear

RPM	1X		2X		3X	
	No Defect	Pitting	No Defect	Pitting	No Defect	Pitting
200	0.0471	0.0526	0.0037	0.0369	-	0.017
300	0.0335	0.0512	0.0137	0.0521	0.0061	-
400	0.025	0.117	0.0131	-	-	0.0225
500	0.0883	0.313	0.0364	0.0832	-	0.0455
600	0.213	0.285	0.0098	0.0298	0.0412	0.0801
700	0.122	0.145	0.0301	0.111	0.211	0.0456

D. Order Tracking or Angular Domain Analysis

The vibration trend of order signal is same as spectrum signal; the speed of faulty gear shaft is counted as first order. And every 45th order represent gear mesh frequency irrespective of shaft speed. Order signal for healthy and defective gear at the speed of 400rpm and No-load is shown in fig-14 and 15.

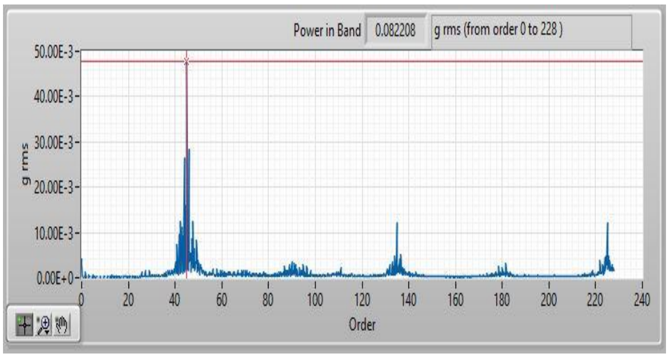

Fig -14: Order Signal of Healthy 20MnCr5 Gear at Speed of 400RPM and No Load

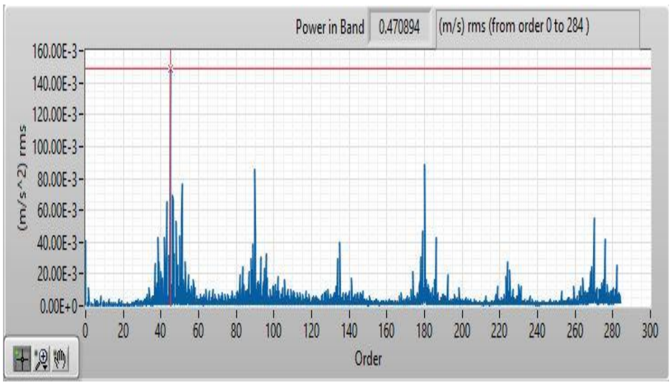

Fig -15: Order Signal of Defective 20MnCr5 Gear at Speed of 400RPM and No Load

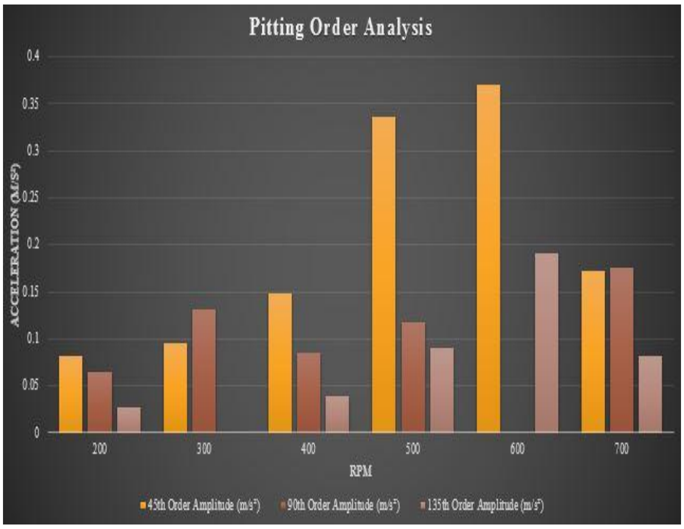

Fig -16: Order Data for Defective 20MnCr5 Gear

Table -3: Order Data Defective 20MnCr5 Gear

RPM	45th Order Amplitude (m/s^2)	90th Order Amplitude (m/s^2)	135th Order Amplitude (m/s^2)
200	0.08141	0.064	0.02643
300	0.09625	0.13189	-
400	0.1489	0.08599	0.03974
500	0.33591	0.11811	0.09027
600	0.36997	-	0.19125
700	0.17292	0.17576	0.08103

4. CONCLUSIONS

The following conclusion can be drown from the experiment conducted:

- High amplitude is observed at 1xGMF with excitation of natural frequency which indicates Pitting tooth defect.
- The amplitude of sidebands will help in determining the defective gear.
- High amplitude is observed at 45th Order with excitation of natural frequency this is the indication of Pitting tooth defect.
- The result given in order analysis is easy to interpret and study the defect in gearbox.

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