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Fault Diagnosis of Gearbox Having Delrin Gear by Vibration and Noise Signal Analysis

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ABSTRACT

The main objective of this study is to detect gearbox fault signals through vibration and noise signal analysis. Experimental tests were carried out using several sets of Healthy and faulty Delrin gears under different speeds and different loads. Initially, Healthy Delrin gears were assembled in the gearbox test rig and signals were sensed using accelerometer and microphone and recorded using data acquisition systems (DAQ) to know the standard behavior of normal gears. Then, the Healthy Delrin gears were replaced by faulty Delrin gears and signals were recorded for each one of the cases separately under the same condition. After that, five proposed techniques of measuring vibrations and noise, namely; Time domain analysis, Frequency Response Function(FRF), Fast Fourier Transform(FFT), Angular domain analysis, and Octave Band Analysis are employed to evaluate the gearbox defects. As of experimental results, it was establish that the vibration and noise signals play a significant role in evaluation of defects in the gearbox. Finally, it is found that the vibration amplitudes of the gearbox are increased resulting in increased tooth breakage under different speeds and different loads.

Keywords:-*Gearbox, Delrin gears, Time Domain Analysis, Frequency Response Function(FRF), Fast Fourier Transform(FFT).*

INTRODUCTION

Throughout the automobile industry, gearboxes are used to transfer the power from engine to wheels [1]. Gears are one among the foremost significant parts in mechanical transmission systems. It's critical element during a sort of industrial applications such as, transportation, aerospace, energy, agricultural sectors, wind power and other fields. Owing to its rugged work settings, breakdown of gears normally triggers mechanical shutdowns, sometimes casualties. As a result, the condition monitoring and fault diagnosis for gears are of great importance in safeguarding the operational safety of systems [2].

Delrin is one of the most crystalline engineering thermoplastic available. It is specified for top load mechanical applications and precision parts, where strength, stiffness, stability and reliability are important. Delrin is tough, light weight, durable acetal homopolymer with low friction, low wear, low noise, low moisture pickup, with excellent spring back properties. Recyclable As a thermoplastic material, Delrin can be recycled using industry standard recovery techniques Delrin is the stiffest and strongest unreinforced engineering polymer available which is natural replacement for metals.

Tooth fracture is one of the most hazardous kind of gear failure and it leads to impairment of the drive and frequently damages the other components (shafts, bearings, etc.) by pieces of the broken teeth. Tooth breakage could be the result of high overloads, repeated overloads causing low-cycle fatigue, or multiple repeated loads resulting to high cycle fatigue of the material Vibration Analysis is a non-destructive technique or procedure that allows the early identification of machine problems by measuring vibration. The purpose of measuring vibrations are, to validate that frequencies and amplitudes do not go beyond the material limits (e.g. As described by the Wohler curves), avoid excitation of resonances in certain parts of a machine, to be able to dampen or isolate vibration sources, to make conditional maintenance on machines, to construct or confirm computer models of structures (system analysis). In order to quantify vibration first make vibration measurements. Then analyze the results (level and frequencies).

Noise is generally Complex acoustic vibrations and annoying, noise is multi frequency (complex) and undesirable. Continuous exposure to noise greater than 78db(A) can cause temporary threshold shift (temporary loss of hearing) temporary loss can be recovered subsequently in quiet environmental and at 95db(A) for 30 years (8hrs/day, 5days/week) may cause permanent threshold shift (permanent loss of hearing). Noise also has an effect on work output, about 20-25% are affected permanently at 90db(A), noise level in excess of 90db(A) leads to increase mistakes, failure to notice unexpected events, loss of attention. A quite atmosphere is a must for effectiveness of managerial function, introspective initiatives, and pursuing intellectual tasks.

METHODOLOGY

Fig.1:-*Experimental setup of gearbox test rig for noise analysis.*

Fig.2:-*Experimental setup of gearbox test rig for vibration analysis.*

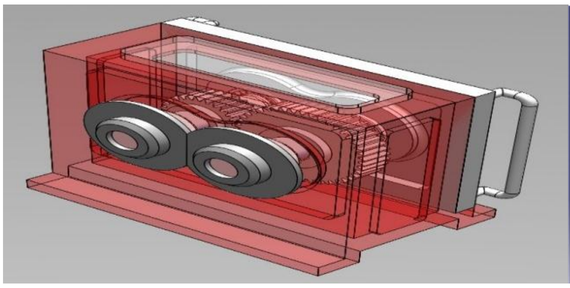


Fig.3:- *Gearbox CAD model.*

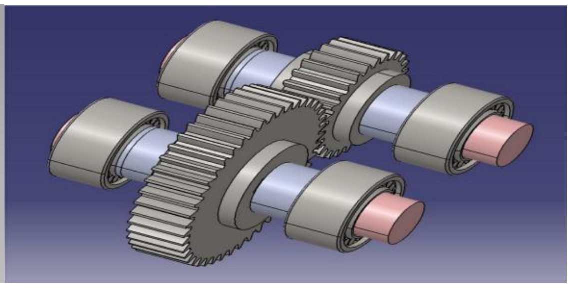


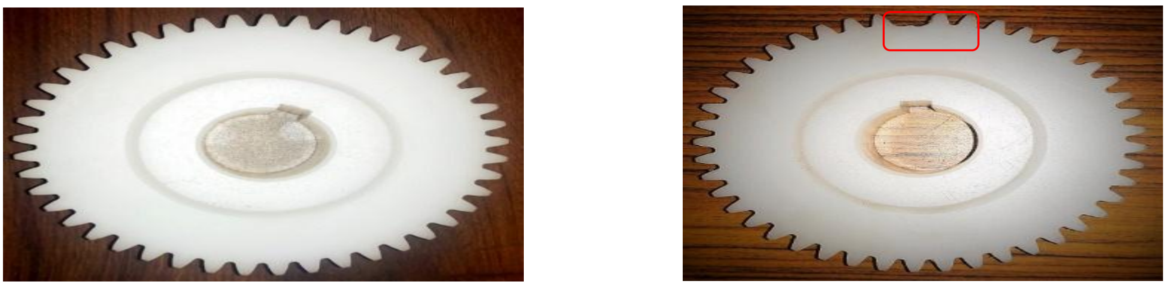
Fig.4:-*Gear assembly*

The experimentation is conducted for both healthy and faulty condition of Delrin gears. The operating speed is varied using the variable frequency drive (VFD) from 200-1000RPM at 100RPM increments. The accelerometer is mounted in radial direction on the bearing as shown in Figure 2 to sense and acquire the vibration data. The microphone is kept closer to the gear mesh region as shown in Figure 1 to sense and acquire the sound pressure or noise level. Both accelerometer and microphone is connected to DAQ (Data Acquisition Control) for the respective measurements. 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 loads. Frequency response function (FRF) analysis is carried out to estimate modal parameters of the gearbox by conducting impact hammer test using Vibrosoft software. The FFT and order tracking is carried out for vibration analysis, and one-third octave band is carried out for noise analysis using Vibrosoft analysis software.

The test rig comprises of two sets of spur gear pairs one acting as test gear pair and the other as master gear pair. The gear pairs each have a 45/28 teeth ratio. The test rig has facility for easy assembly and disassembly of test gear pairs. The Gear pair specifications used in the present work are given in Table 1.

Table 1:-*Specifications of gear pair*

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



a. H *b. F*

Fig.5:- *Different Types of Faulty Delrin Gears.*

Healthy gear	H
Gear with one broken tooth	F

Table 2:-*Gear designation*

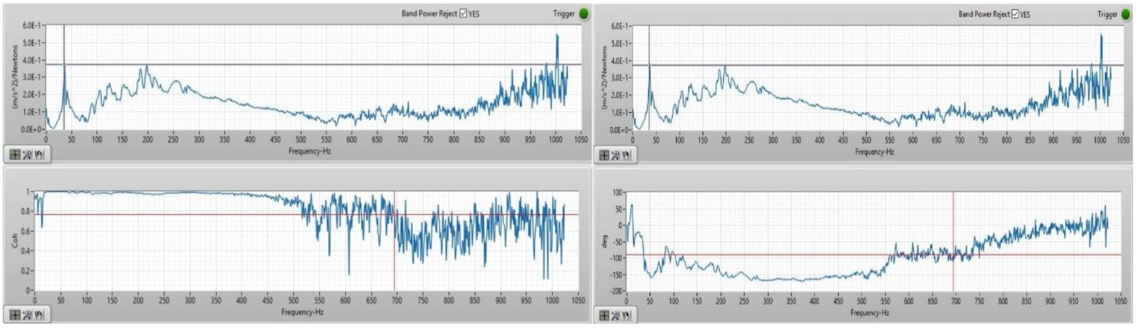
Gears designation is shown in Table 2.

RESULTS AND DISCUSSION

A. Frequency Response Function (Frf)

Impact testing is used for FRF measurements. An ideal impact will excite potentially all frequencies equally. In terms of Fourier analysis this means that the Fourier transform of theoretical, zero width impulse has a uniform spectral amplitude at all frequencies. Impact excites all frequencies with equal energy. Only natural frequencies responds more to the excitation and hence response is not equal. The frequencies whose response is high are the natural frequencies of the system. The impact hammer test was conducted on the gearbox at 3 different locations with the help of the impact hammer.

Figure 6 shows FRF of the equipment obtained from impact hammer test. Some of the modal frequencies obtained from the FRF are 35Hz, 41Hz, 91Hz, 104Hz, 124Hz, 185Hz and 197Hz.



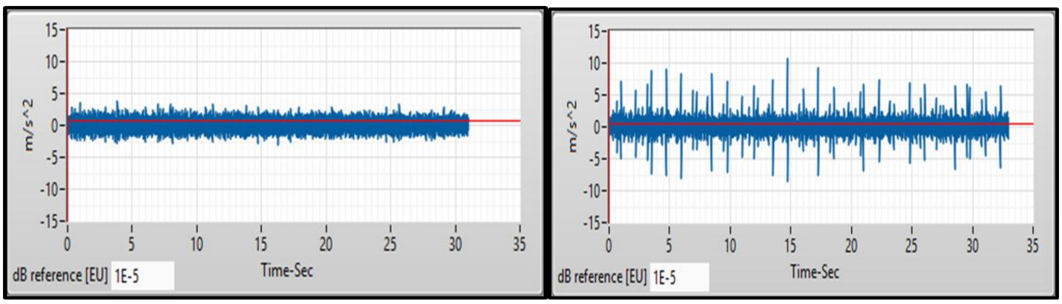
a. Magnitude and Coherence. *b. Magnitude and Phase Angle.*

Fig.6:-*FRF Signal of Gearbox.*

B. Time Domain Analysis

The above time waveform plot illustrates how the signal from an accelerometer probe appears when graphed as amplitude over time. This form of vibration plot is correspondingly called a time domain plot or graph. Time waveforms shows a short time sample of the raw vibration. The sample time record of the input signal is displayed on the single frame. The analyzer is used in oscilloscope mode. When time waveform is obtained in FFT analyzer the anti-aliasing filters are to be made ineffective to view all the frequencies. Time waveform analysis can provide clues to machine condition that are not always evident in the frequency spectrum and, when available, should be used as part of the analysis program.

The time domain signals of gearbox casing for healthy and faulty delrin gears are shown in Figure 7



a. H *b. F*

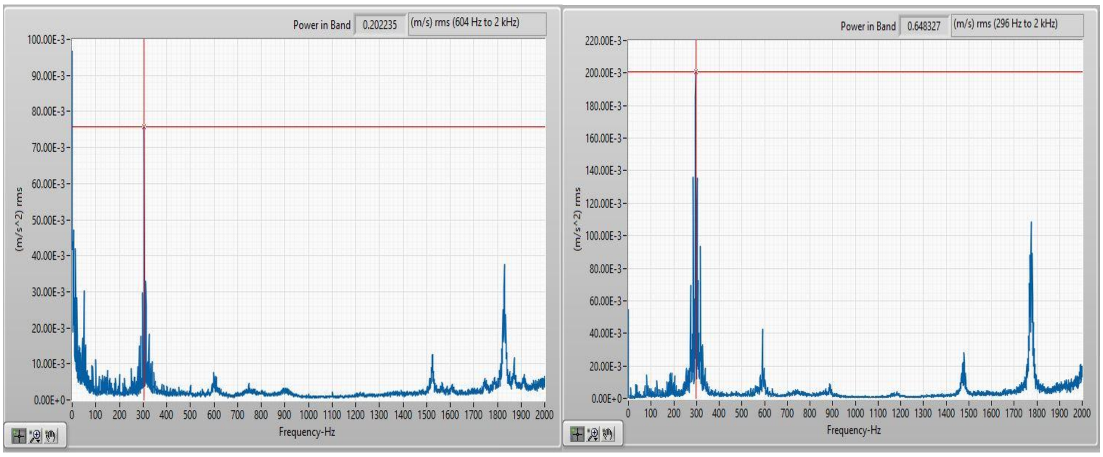
Fig.7:-*Time Domain Signals of Gearbox Casing for Healthy and Faulty Gears*

Research and Development in Machine Design
Volume 3 Issue 2

C. Frequency Domain Analysis

The frequency spectrum gives in many cases a detailed information about the signal sources which cannot be obtained from the time signals. The measurement and frequency analysis of the vibration signals measured on the gearbox. The frequency spectrum provides information about the level of vibration caused by rotating parts and tooth meshing. This here by becomes a helpful aid in detecting sources of increased (undesirable) vibration from these and other sources. A method of displaying the vibration signal is to apply a Fast Fourier Transformation (FFT) in a way that is more useful for analysis. In non-mathematical terminology, this means that the signal is split down into specific amplitudes at various component frequencies. Frequency domain signals obtained after carrying out FFT of time domain signals.

For the gear speed of 400RPM, gear shaft and pinion shaft frequencies are 6.67Hz and 10.72Hz respectively and the corresponding Gear Mesh Frequency (GMF) is 303Hz. Dominant peaks can be observed at GMF which are increasing with the number of broken teeth. The vibration level of healthy gear in Figure 8(a) as it is low when compared to other faulty gear conditions shown in Figure 8(b). From the zoomed spectra Figure 9 can be observed that sidebands with significant strength appear in case of defective gear when compared to that in healthy gear.



a. H *b. F*

Fig.8:-*FFT Signals of Healthy and Faulty Gears at Speed of 400RPM and 5KG Load.*

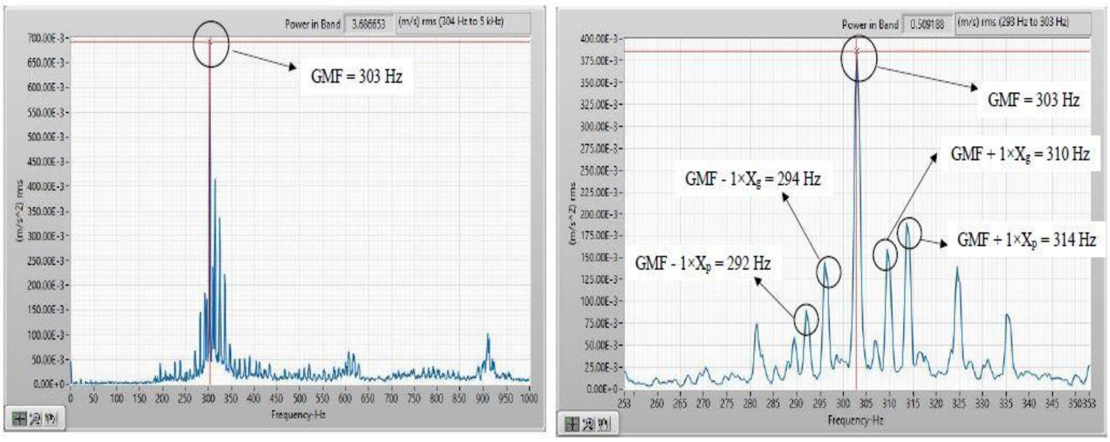


Fig.9:- *Zoomed FFT Signals of Healthy and Faulty Gears at Speed of 400RPM and 5KG Load Around GMF.*

D. Order Tracking or Angular Domain Analysis

In order tracking, the rotational frequency is the tracked and used for analysis with the help of order spectrum. This implies that the harmonic or sub-harmonic order component stays in the same analysis line independent of the speed of the machine. An order spectrum provides amplitude and/or phase of the vibration and acoustic signal as the function of the harmonic order of rotational frequency.

Order tracking analysis of vibration and acoustic signal from rotating machinery is favored in terms of order spectrum than frequency spectrum. Because, most of the dynamic forces exciting the machine (such as gear, bearing fault etc.) are kinematically related to rotational frequency, hence interpretation and diagnosis can be simplified by order analysis. In case were machine speed is changing, the problem of smearing of the frequency component is solved by order analysis. Analysis of noise and vibration from the rotating machinery during run up and cost down is possible by order tracking. Determination of critical speed of a rotating shaft when the speed is changing.

The order signals vibration trend is same as spectrum signal, the first order is credited as speed of faulty gear shaft. And every single 45th order signify gear mesh frequency irrespective of shaft speed. Order signal for healthy and faulty gearbox at the speed of 400rpm and load 5KG is shown in Figure 10. The GMF is in 45th order which depends on the number of teeth in a tracking gear and its harmonics are appear at 90th, 135th, 180th orders etc. the difference between GMF and its sidebands are easily identified in order analysis.

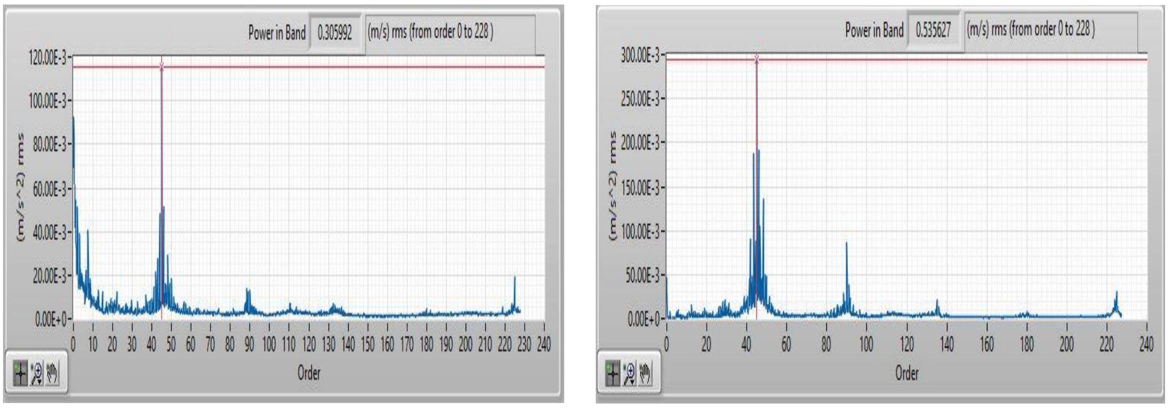


Fig.10:- *Order Signal for Healthy and Faulty Gears at the Speed of 400RPM and Load 5KG.*

E. Octave Band Analysis

Octave Band are continuous range of frequencies in which the succeeding frequency limit is twice the preceding frequency limit. And One third Octave band is the Ratio of succeeding and preceding frequency limit is 1.260:1(i.e.$2^{1/3}$).

It is observed that the noise level is constantly about 95 dB(A) which is considered harmful for human ear if exposed to long hours. The operating condition noise analysis is same as used for vibration analysis. Figure 11 shows the octave band signal acquired for healthy and faulty gears at the Speed of 400RPM and Load 5KG.

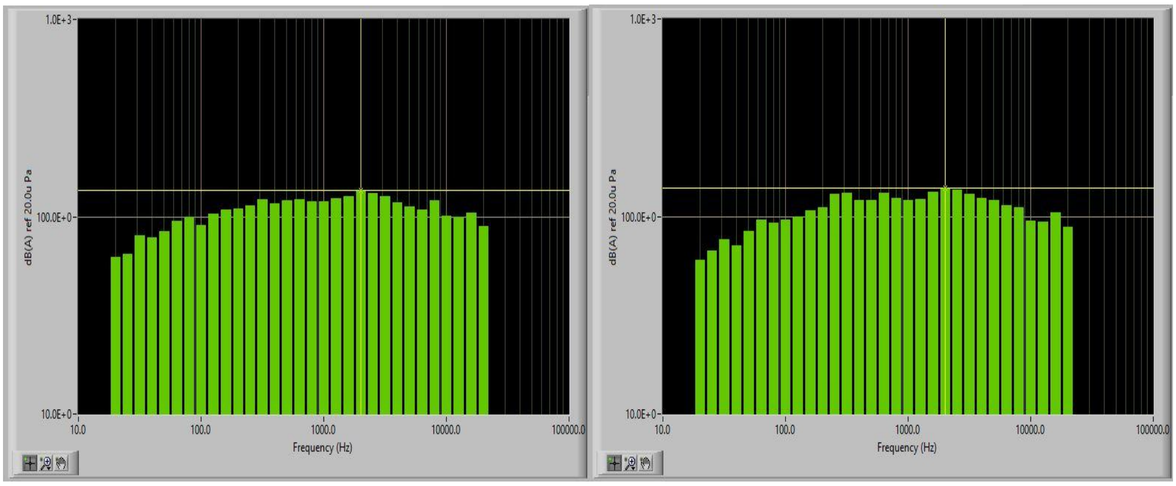


Fig.11:- *Sound signal with 1/3 octave for healthy and faulty gears at the speed of 400rpm and load 5kg.*

CONCLUSIONS

The following conclusions are drawn from the vibration and noise characteristics of gearbox, obtained from the study.

Time Domain Analysis shows number of pulses for every single revolution of shaft that depends on the number of broken teeth in the gear. This is strong indication of existence of broken teeth (defect) of the gear in the gearbox.\

FFT signals display dominant peaks at gear mesh frequencies, whose magnitude are observed to increase with the number of broken teeth. And the sidebands amplitude will help in determining the defective gear.

The Broken teeth defect can be identified by FFT when we see peak at 1XGMF and have excited natural frequency of gear. And the Broken teeth defect can also be identified by close studying the time domain data.

Noise analysis is useful for early diagnosis and to maintain safe working environment with respect to the level of sound.

The noise level increases for higher speed and higher load conditions. Noise signals are to be processed in anechoic conditions for eliminating the influence of surrounding noise effects, so that the noise due to faulty gears are distinctly recognized.

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