Fault Detection of Double Stage Helical Gearbox Using Vibration Analysis Techniques

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Abstract: Fault detection in gearbox from vibration data is difficult task and is important to detect fault while they are still developing. The aim of this paper is to improve reliability, safety & productivity of gearbox using different non-destructive inspection methodologies and processing acquired waveforms with advance signal processing techniques. For detecting different types of gear fault an experimental data is taken from double stage helical gearbox set-up with help of FFT analyzer. MATLAB is utilized for identifying the advancement of gear defect taking into account time-frequency analysis. Fault manifesting in impulse like vibration signals are focused on, which include faults such as missing of tooth, crack at gear, removal of tooth etc. By comparing signal of faulty condition with healthy condition through FFT analyzer, we can easily predict behavior of fault. For validation we are using MATLAB program which gives us statistical parameter in time & frequency domain analysis. The genuine position in angle of revolution for one tooth missing in gearbox is likewise discovering by MATLAB program.

Index Terms—: Gear, one tooth missing, fault detection, FFT, MATLAB program.

I. INTRODUCTION

WITH continuously increasing market globalization and corporate consolidations, every company's survival in the gearbox industry depends on its ability to compete. Consumer is always on the watchtower for the lowest prices for a given product quality. To meet this lowest price, without affecting the profit margin, industry turns to minimizing the production and operation costs. To sustain the required production levels leaving no room for delay associated with machinery breakdown. A proper maintenance strategy aims to maximize machinery availability and minimize unplanned breakdowns. The governing of a Gearbox is a crucial activity because it is importance in power transmission in any industry. Strategies, for example, wear, debris analysis as well as acoustic emissions need availability to the gearbox to gather samples near the gearbox. Vibration analysis is one of the most_important conditions monitoring technique that are applied in real life.

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II. LITERATURE REVIEW

Most of the defects experienced in the rotating machinery give rise to a clear-cut vibration pattern and hence predominantly faults can be recognizing using_vibration analysis techniques. Fault detection in gears has been the subject of minute examination and many methods base on vibration signal analysis have been developed. Traditional methods include power spectrum, crest factor, kurtosis, cepstrum approximation, time-domain averaging as well as demodulation, which have proved to be effective in fault diagnosis [1] [2].

The intention of using gears in machinery is primarily to transfer power and rotary motion between shafts while maintaining the calculated angular velocity ratio with fine motion transfer and high-level efficiency. A crack in the tooth root is the least desirable damage caused to gear units and often leads to failure of gear unit operation. A possible damage in gear units can be identified by monitoring vibrations. Amplitudes of time signal are, by frequency analysis, presented as a function of frequencies in spectrum with time frequency analysis. Diagnostics is interested in the definition of the current condition of the system and the location, shape and reason of the damage formation. The form of damage is identified on the basis of deviations from the undamaged gear system. A fatigue crack present in the tooth root causes significant changes in tooth stiffness and the dynamic response is different from the one caused by an undamaged tooth [3] [4].

Gearbox condition monitoring is an essential process because of it is importance in power transmission in all industry. Techniques such as wear, debris analysis as well as acoustic emissions need availability to the gearbox to gather samples near the gearbox. Vibration analysis is most-favored condition monitoring techniques that are employed in actual life. Large number of the defects came across in the rotating machinery give accession to a separate vibration pattern therefore almost all faults can be acknowledged using vibration analysis techniques. Vibration Monitoring is the method of recording and describing vibration signatures which commits this technique is very powerful for monitoring rotating machineries. We can detect the fault in gearbox by the rendition of spectrums and vibration data. When gearbox is running on full load conditions spectrums give the fault in gearbox [5] [6].

Gears are often critical and important elements in the gearbox requiring the application of condition monitoring techniques. The degree of wear debris and load to which they

are subjected to normal operating conditions that means they are often subjected to untimely failure. 60% to 70% of gearbox failures are due to defects which produce in the gears, and all of these are due to particular defects like fatigue induced fractures. To find out the condition of these gears by parameters like vibration, oil contamination, wear debris, noise, temperature. Change in whatsoever of these parameters called as 'signatures' signature shows the health of the gears its condition. Fault identification is conducted in the following ways: data acquirement, feature insertion, and fault recognition and identification. We know that an alternate crack propagation scenario which expects that a crack propagates in the tooth root in both the break profundity course. The width direction all the while, and which is more reasonable for non-uniform load distribution cases than the other presented scenarios. Also an examination of the execution of two time domain indicators [i.e. the RMS and kurtosis] for three distinctive crack progression scenarios, to look at these scenarios from fault detection point of view. The impact of various crack progression circumstances on crack can be detected using conventional vibration analysis [9].

Another technique for monitoring the advancement of gear faults in light of the count of local energy density is introduced. A hypothetical model for a gear pair with a tooth root split was created. Experimental results from a test apparatus were analyzed utilizing the continuous wavelet transform and the energy density of the vibration signal connected with the meshing of faulty gears was ascertained. It was demonstrated that the local energy is a delicate element for surveying fault magnitude. An observational law, which relates the energy content to the depth of the crack, was set up. A distinction signal is initially developed by evacuating the standard meshing components and sidebands from the time found the time averaged data. For a healthy gear the distinction signal is basically noise bringing about a normalized kurtosis value of three the normalized kurtosis value increments past nominal value of three if a gear tooth builds up a defect [10].

Increased order for minor production and maintenance expenses means that the condition monitoring of gear transmissions has turn out to be an essential area to industry ever since early on detections of defects in them can avoid failures in the machines. Machine condition monitoring helps guarantee the dependability and low-priced operation of industrial amenities. Condition monitoring can give premature detection of machine defects in order that suitable action can be in use before that defect causes breakdown. Incessant condition monitoring permits a machine restore and maintenance to be designed hence economical operation should improve and reduce probable dangerous emissions. The frequency of the vibrations can likewise be mapped, when certain frequencies will be available. The conditions then show about the approaching imperfection of that framework. Correlation of the vibration spectra of new gear against hardware that has been utilized will give the data and settle on a choice, whether the maintenance is required. Gearboxes are frequently basic segments of machine requiring the use of condition monitoring procedures. Condition checking of Gearboxes suggests determination of state of gears and its change regarding time. The state of these gears might be controlled by the physical parameters like noise, oil contamination, temperature, wear debris, vibration, etc. An adjustment in any of these parameters called "signatures " would in this manner demonstrate the adjustment in the condition of the gears.

Vibration signals gathered from sensors and after that prepared are regularly contaminated by some noise and can along these lines be unusable for specifically diagnosing machine flaws [8]. Four instances of experimental vibration signatures are inspected: untouched gear, preset gear tooth harm as it were. Keeping in mind the end goal to give better essential comprehension of the vibration signatures, each of the four cases above are analyzed and thought about in the time domain, the recurrence area, and the joint time frequency domain. Results got from three distinctive signal domains are analyzed to create conceivable characteristic parameters that gauge the trustworthiness and the wellbeing of gear parts [7] [8].

III. EXPERIMENTATION

A. Experimental Set Up

In order to evaluate fault in gearbox using vibration techniques, experimental work was carried out on a gearbox test rig. The gearbox test rig comprises of a 3-stage induction motor, a two phase helical gearbox, shaft couplings and load device(rope brake dynamometer), as appeared in Figure 2. The gearbox comprises of two-phase helical gear transmissions. It was decided for this examination not just on the grounds that it is generally utilized as a part of industry, additionally on the grounds that it permits faults to be easily simulated and different CM methods to be broadly assessed.

It is preplanned to create defect, such as removal of tooth, crack at gear, two corner defects and one corner defect in the gearbox. Vibration analysis of each defect is carried out independently. For that reason, gears of identical specifications are used and on each gear separate faults are created. Vibration of every defective gear and gear without any defect is also obtained. Therefore signals obtained is analyzed which are important for the fault identification. Details of gearbox & the gears are given below in Table I and Table II.

TABLE I
SPECIFICATIONS OF GEARBOX

Sr. No.	Particulars	Specifications
1	Power	0.5 Hp
2	Input rpm	1200
3	Frequency of input	1200/60 =20 Hz
4	Output rpm	150
5	Frequency of output	150/60 = 2.5Hz
6	Number of stages	2

TABLE II
SPECIFICATIONS OF GEARS

	Stage 1		Stage 2	
Particulars	Gear	Pinion	Gear	Pinion
Type	Helical		Helical	
Tooth Profile	20°		20°	
Helix Angle	15°		15°	
P.C.D.	132.52	41.41	69.88	27.95
NO. Of Teeth	64	20	45	18
Face Width	28	28	21	21
Shaft Diameter	20	20	15	20
Key	5X5X32	5X5X32	4X4X32	5X5X32
Addendum	136.65	45.45	136.65	45.45
Dedendum	127.35	36.23	72.98	31.05
Bearing	6004Z		6004Z	
Speed	375	1200	150	375
Material	C45		C45	

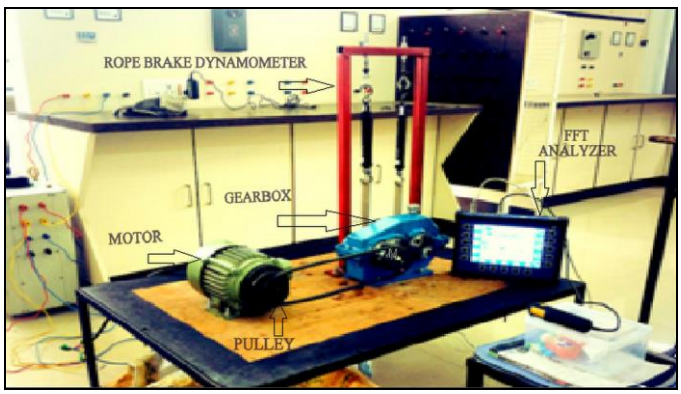

Fig. 1.Experimental set up

Fig.1. is an illustrative photograph of the test rig and gearbox used in this study.AC motor is connected to input of the gearbox which is again coupled to gear shaft using coupling. Rope brake dynamometer is connected to output shaft of gearbox. Hence by using gearbox, power is transmitted from motor to dynamometer. Fig.1. shows *Experimental set up* vibration estimation for defect finding of gearbox utilizing FFT analyzer.

B. Test Procedure

In this, gearbox is permitted to run at its permitted speed and power by applying diverse load states of 0 kg, 1 kg, 2 kg, 3 kg on rope brake dynamometer which having radius of pulley 55 mm. Magnetic base accelerometer is locate on the top just below the place of bearing in radial & axial direction of a gearbox. Then, healthy gear readings are taken at different loading condition. Gears having different faults with various applied load conditions. This data is saved & stored in FFT analyzer for remaining analysis. Two different gears are used in gearbox assembly for generation of faults on gear tooth profile. Then most General types of faults created are as follows; one tooth missing , two corner defect, one corner defect , improper lubrication, wear formation. Out of which for analysis purpose, we considered one tooth missing fault. Refer Fig. 2.

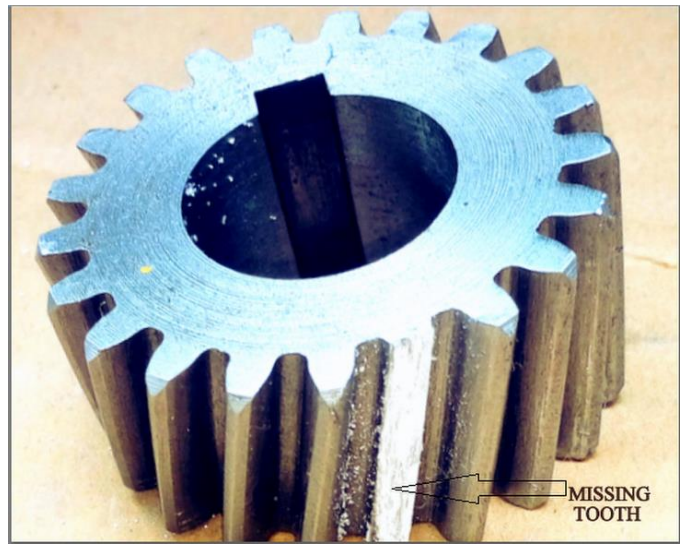

Fig. 2.Removal of one teeth

C. Processing of signal

Signal processing is carried out by MATLAB program where .csv and .wav files is input data and output data is in the form of waveform like a] Time Vs Amplitude b]Frequency Vs Acceleration c]Degree Vs Amplitude d] Time Vs Degree. MATLAB program is used to determining the 24 parameters along with parameters like kurtosis, standard deviation, crest factor, RMS are also determine. The MATLAB program is use to get different waveform like frequency domain, time domain.

TABLE III
DETAILS OF STATISTICAL PARAMETERS

Time Domain Parameter	Frequency Domain Parameter
$P1=\frac{\sum_{n=1}^{N} x(n)}{N}$	$P12=\frac{\sum_{k=1}^{K} s(k)}{K}$
$P2=\sqrt{\frac{\sum_{n=1}^{N}(x(n)-p1)^2}{N-1}}$	$P13=\frac{\sum_{k=1}^{K}(s(k)-p12)^2}{(K-1)}$
$P3=\left(\frac{\sum_{n=1}^{N}\sqrt{\lvert x(n)\rvert}}{N}\right)^2$	$P14=\frac{\sum_{k=1}^{K}(s(k)-p12)^3}{K(\sqrt{p13})^3}$
$P4=\sqrt{\frac{\sum_{n=1}^{N}(x(n))^2}{N}}$	$P15=\frac{\sum_{k=1}^{K}(s(k)-p12)^3}{K(p13)^2}$
$P5=\max\lvert x(n)\rvert$	$P16=\frac{\sum_{k=1}^{K} f_k s(k)}{\sum_{k=1}^{K} s(k)}$
$P6=\frac{\sum_{n=1}^{N}(x(n)-p1)^3}{(N-1)p2^3}$	$P17=\sqrt{\frac{\sum_{k=1}^{K} s(k)(f_k-p16)^2}{K}}$
$P7=\frac{\sum_{n=1}^{N}(x(n)-p1)^4}{(N-1)p2^4}$	$P18=\sqrt{\frac{\sum_{k=1}^{K} s(k)(f_k)^2}{s(k)}}$
$P8=\frac{p_5}{p_4}$	$P19=\sqrt{\frac{\sum_{k=1}^{K} s(k)(f_k)^4}{\sum_{k=1}^{K} s(k)(f_k)^2}}$
$P9=\frac{p_5}{p_3}$	$P20=\frac{\sum_{k=1}^{K} s(k)(f_k)^2}{\sqrt{\sum_{k=1}^{K} s(k)(f_k)^2 \sum_{k=1}^{K} s(k)}}$
$P10=\frac{p_4}{\frac{1}{N}\sum_{n=1}^{N}\lvert x(n)\rvert}$	$P21=\frac{p_{17}}{p_{16}}$
$P11=\frac{p_5}{\frac{1}{N}\sum_{n=1}^{N}\lvert x(n)\rvert}$	$P22=\frac{\sum_{k=1}^{K} s(k)(f_k-p16)^3 s(k)}{K(p17)^3}$
	$P23=\frac{\sum_{k=1}^{K} s(k)(f_k-p16)^4 s(k)}{K(p17)^4}$
	$P24=\frac{\sum_{k=1}^{K} s(k)(f_k-p16)^{\frac{1}{2}} s(k)}{K\sqrt{p17}}$

IV. DISCUSSION AND RESULT

A. One Tooth Missing [OTM] Condition

1) Using Spectral Analysis

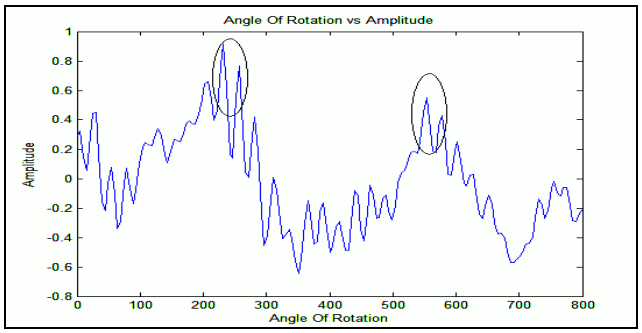

Fig. 3. Missing Tooth Condition (1000rpm) in MATLAB

From Fig. 3, it can be observed that, amplitude of acceleration is increased abruptly by nearly 200°-210° of angle of rotation of gear and again for second revolution , amplitude of acceleration goes high at 560°-570° of angle of rotation of gear for one revolution. While actual position of missing gear tooth in OTM condition is nearly about 210° from direction of rotation of gear hence we can say that the position of missing gear tooth is known which is at 200°-210°.

B. Using Time Domain Analysis

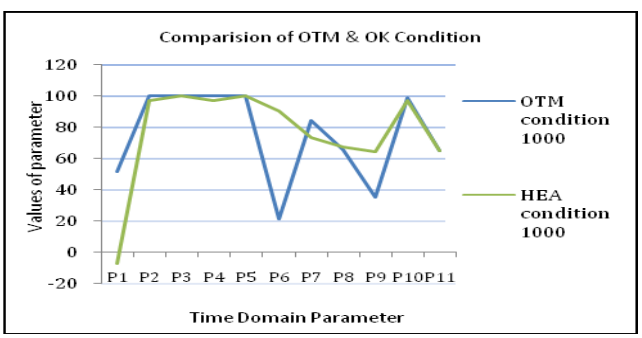

Fig. 4. plot for Comparison of OTM & HEA Condition Vs Time Domain Parameters at 1000 rpm

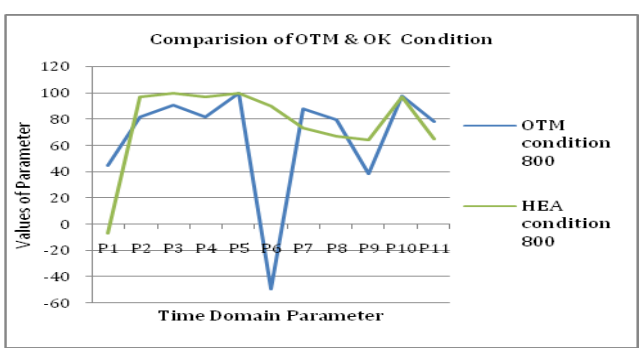

Fig. 5. plot for Comparison of OTM & HEA Condition Vs Time Domain Parameters at 800 rpm

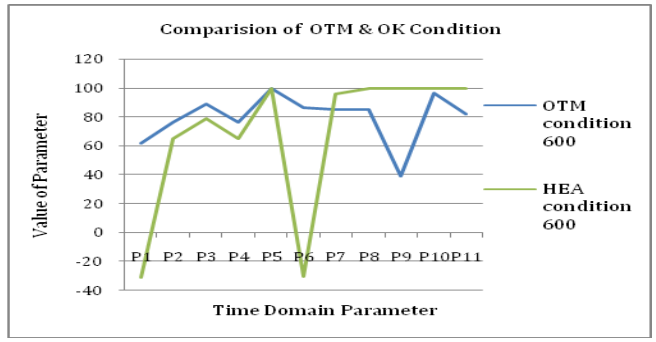

Fig. 6. plot for Comparison of OTM & HEA Condition Vs Time Domain Parameters at 600 rpm

C. Using Frequency Domain analysis

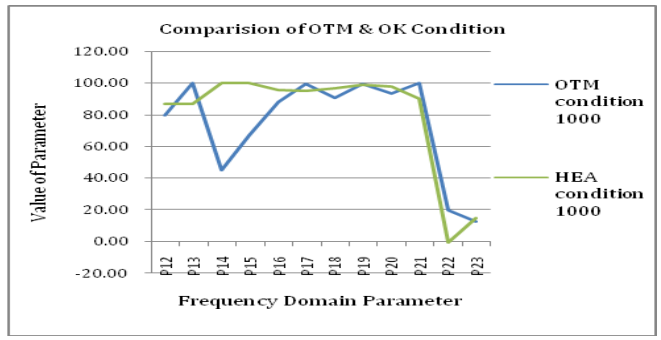

Fig. 7. plot for Comparison of OTM & HEA Condition Vs Frequency Domain Parameters at 1000 rpm

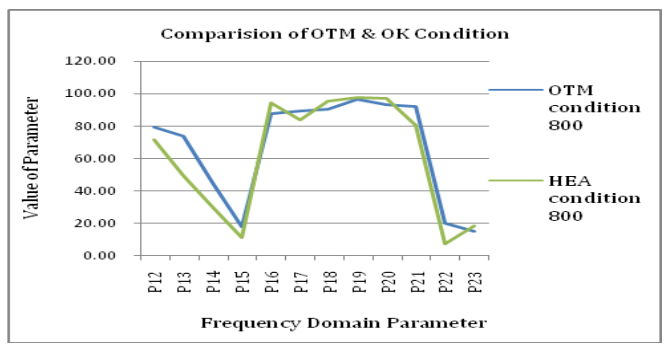

Fig. 8. plot for Comparison of OTM & HEA Condition Vs Frequency Domain Parameters at 800 rpm

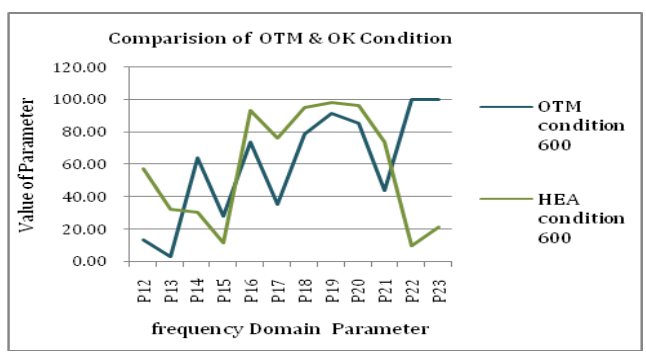

Fig. 9. plot for Comparison of OTM & HEA Condition Vs Frequency Domain Parameters at 600 rpm

The above graphs show comparison of time domain parameters (P1 to P11) in figure number 4, 5, 6 & frequency domain parameters (P12 to P24) in figure number 7, 8, 9. These parameters are calculated by using signal data with respect to one tooth missing condition at 600rpm, 800rpm and 1000rpm. The corresponding Observations are as follows:

D. From graph of time domain parameter;

1) P1 parameter is having minimum value in HEA (healthy) condition whereas value of P1 parameter has increased in OTM (one tooth missing) condition.
2) Parameters like P2 TO P5 are having constant value in HEA (healthy) condition whereas in OTM (one tooth missing) condition these parameters have linearly decreased in their value.
3) P6 & P9 Parameters have maximum value in HEA (healthy) condition as compared to OTM (one tooth missing) condition.

E. From graph of frequency domain parameter;

1) The parameters like P15 & P22 having minimum value in HEA (healthy) condition whereas value of this parameters have increased in OTM (one tooth missing) condition.
2) P16 Parameter has maximum value in HEA (healthy) condition as compared to OTM (one tooth missing) condition.
3) P18, P19, P20 have linearly decreased variation in their value as compared to HEA (healthy) condition.

V. CONCLUSION

1) The missing of one tooth of gear can be perceived by using essential time domain parameter such as P1, P2, P3, P4, P5, P6 and P9 in figure number 4, 5, 6.
2) Frequency domain parameter like P15, P16, P18, P19, P2O, and P22 can also used to detect missing of tooth in gear.
3) This method is very impressive to analyze the various types of defects in gearbox.
4) The peaks are available at multiples of frequencies and sub-harmonics. The multiples of frequencies and sub harmonics are due to the presence of fault in the Gearbox system.
5) This paper has examined the Gear fault detection using feature extraction parameters i.e. time & frequency domain parameter and vibration monitoring.
6) The one tooth missing position is perceived by observing the graph in MATLAB of two revolution of gear tooth at an angle of just about 210°.

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