

Fault Detection Techniques in Two Stage Helical Gearbox by using Vibration Analysis

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ABSTRACT: The condition monitoring of a lab-scale, two stage, gearbox using different non-destructive inspection methodologies and the processing of the acquired waveforms with advanced signal processing techniques is the aim of the present work. Acoustic emission (AE) and vibration measurements were utilized for this purpose. The experimental setup and the instrumentation of each monitoring methodology are presented in detail. Emphasis is given on the signal processing of the acquired vibration and acoustic emission signals in order to extract conventional as well as novel parameters–features of potential diagnostic value from the monitored waveforms. Innovative wavelet-based parameters–features are proposed utilizing the discrete wavelet transform. The evolution of selected parameters or features versus test time is provided, evaluated and the parameters with the most interesting diagnostic behaviour are highlighted. The differences in the parameters evolution of each NDT technique are discussed and the superiority of AE over vibration recordings for the early diagnosis of natural wear in gear systems is concluded.

KEYWORDS: Gearbox Vibration, Condition monitoring, Fault diagnosis.

I. INTRODUCTION

In gearboxes and power drive trains in general, gear damage detection is often very critical and can lead to increased safety in aviation and in industry as well. Thus the interest for their periodic non-destructive inspection and/or on-line health monitoring is growing and effective diagnostic techniques and methodologies are the objective of extensive research efforts over the last 50 years. [1]

Fault detection techniques include many parameters which are based on time domain statistical analysis, frequency domain (fast Fourier transform) and time– frequency techniques to detect damage of the gearbox. [2]

Gears have received a lot of attention for their health monitoring. Monitoring can be done using various techniques which utilize the change in one or more physical property during the course of operation of the gear, such as, acoustic emission, thermal imaging, wear debris, sound signal, vibration signal, etc [3]

Gear box is one of the key components in wind turbine and the fault of gear box will lead to wind turbine shut down inevitably. So what must be done is making timely and accurate diagnosis to gear box. [4]

Today, most maintenance actions are carried out by either the predetermined preventive or the corrective approach. The predetermined preventive approach has fixed maintenance intervals in order to prevent components, sub-systems or systems to degrade. The parameters most often chosen to detect this change in conditions are either vibration, which tends to increase as a machine moves away from a smooth running condition into a rough mode with development of a fault, or an analysis of machine noise or acoustics, or machine lubricants where samples are tested for items such as wear debris from a developing fault.

Condition Based Monitoring (CBM):

Condition monitoring of gear box system is of considerable importance to industry since an early detections of faults in them can prevent failures in the machines. The philosophy of machine condition monitoring is to monitor the state of a machine and to detect any deterioration in condition, to determine the cause of this deterioration and to predict when failure can be expected. The result is the maximization of machine availability and maximum utilization of the machine

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elements (bearings, gears etc.) Vibration analysis is the most commonly used technology used to monitor the condition of the machine. The frequency of the vibrations can also be mapped or represented, when certain frequencies will be present. The conditions then indicate about the impending defect of that system. Comparison of the vibration spectra of new equipment versus equipment that has been used will provide the information and make a decision, whether the maintenance is required or not.

II. EXPERIMENTATION

a) EXPERIMENTAL SET UP:

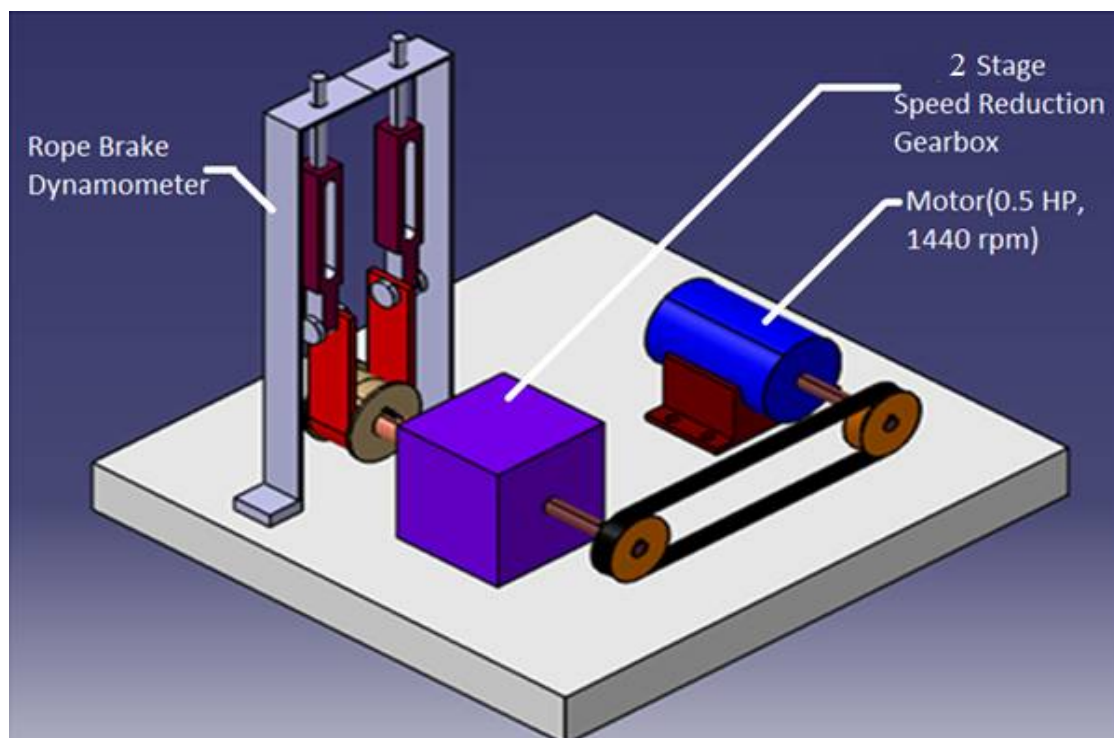


Fig.1: Schematic of the test rig used for the detection of gear faults.

A two stage helical gearbox shown in Fig.2 was used during the tests for the detection and advancement monitoring of faults. It consists of a 0.5HP AC derive motor and variable load rope brake dynamometer. AC motor is connected with belt-pulley mechanism to get rid of the undesired effects of AC motor and misalignments. The motors and gearbox are mounted on a stiffened structure. Four rubber pads were mounted to the structure to introduce additional damping to resulting vibrations which are transmitted from rig to ground or vice-versa.

As seen in Fig.2, the speed of the driving motor and the load at the rope brake dynamometer are adjusted continuously to accommodate the range of speed/torque operating conditions. Both the speed and load controller allow the gearbox to operate in a speed range of 0 to 1200 rpm.

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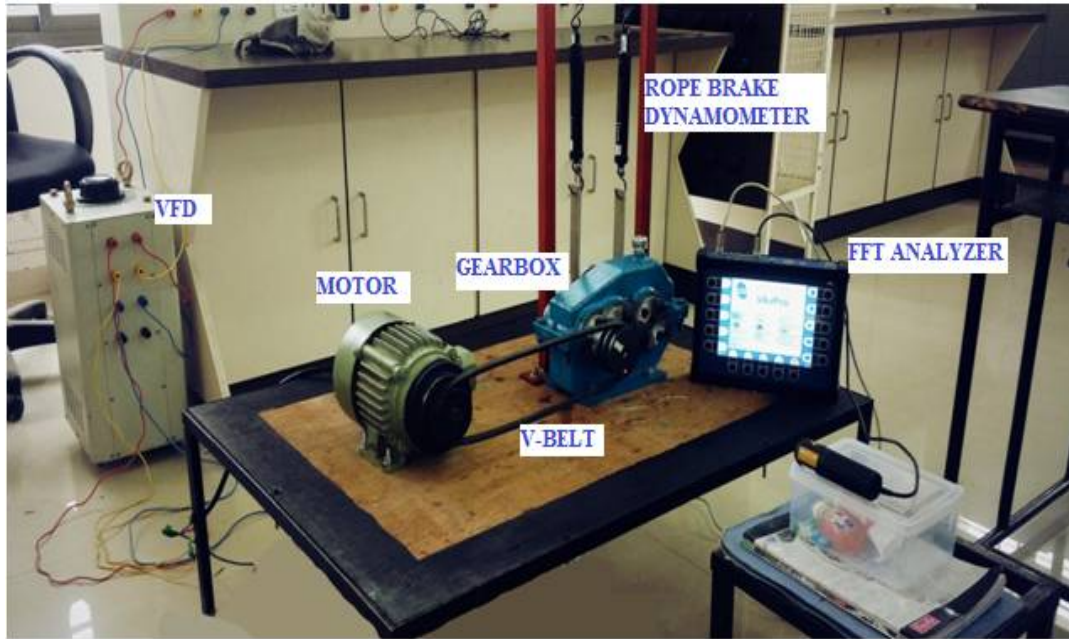


Fig.2: Actual test rig used for the detection of gear faults.

It is decided to make planned faults, such as like wear defect, one tooth is missing in the gearbox. The analysis of vibration of each fault is carried out separately. For that purpose, gears of same specifications is taken. The vibration of each faulty gear and gear without any fault is obtained. Thus the signals obtained is analyzed which are valuable for the fault diagnosis. Details of gears are given in Table 1 & 2.

Table1: First Stage

Sr. No.	Particular	Details
I	Module (Normal)	1.5 mm
II	No. of teeth of Pinion	19
III	No. of teeth of Gear	45
IV	Pressure angle	20°
V	Face Width	21 mm
VI	PCD of Pinion	30 mm
VII	PCD of Gear	70 mm
VIII	Centre Distance	50 mm

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Table2: Second Stage

Sr. No.	Particular	Details
I	Module (Normal)	2 mm
II	No. of teeth of Pinion	21
III	No. of teeth of Gear	64
IV	Pressure angle	20 ⁰
V	Face Width	18 mm
VI	PCD of Pinion	43 mm
VII	PCD of Gear	133 mm
VIII	Centre Distance	88 mm

b) EXPERIMENTAL PROCEDURE:

In experimental procedure the gearbox is allowed to run at its rated power and speeds by applying different load conditions of 0 kg, 2 kg, 3 kg on rope brake dynamometer having diameter of pulley 125 mm. For vibration measurement magnetic base accelerometer is place on the top just below the location of bearing in axial & radial direction of gearbox.

By making all above arrangements, readings are taken for healthy gear and good lubrication condition. This data is stored in FFT analyser for further analysis. Vibration spectrums are taken for gears having various faults and the data is stored in computer for further analysis. For different condition of faults and different load conditions data is collected.

Formation of Faults on Gear Tooth:

For formation of manual faults on gear tooth, one gear is used. For that, the helical pinion of second stage of 21 teeth and module of 2 mm is selected.

The common types of faults of gear tooth are as follows:

1. Wear defect on gear tooth.
2. One tooth missing defect.

Wear defect on gear tooth:

For making this fault, one tooth of gear is wear out by file and original non-defective gear is replaced with this gear.

One tooth missing defect:

For making this fault, one tooth of gear is removed by hacksaw blade and original non-defective gear is replaced with this gear. Fig. 3 shows the actual fault which is done on the gear.



Fig. 3: One tooth missing defect

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Signal processing methodologies:

The processing of signal is carried out by developing the MATLAB program in which the input data is taken from different types of defects in the form of.csv files and output data is in the form of time & frequency waveform. The feature extraction parameters are calculated by using same MATLAB program of respective defect condition. For determining the 24 parameters as per following Table no.3 and additional parameters like standard deviation, kurtosis, RMS , crest factor are also determine along with 24 parameters, The MATLAB program is develop for getting the plot for time domain, frequency domain, one revolution of gear & feature extracted parameters. Collections of the calculated values are in table & then these calculated values get converted in normalized value format [1].

Table 3: Statistical Parameters

Time domain parameters	Frequency domain parameters
$p1 = \frac{\sum_{n=1}^N x(n)}{N}$	$p12 = \frac{\sum_{k=1}^K s(k)}{K}$
$p2 = \sqrt{\frac{\sum_{n=1}^N (x(n)-p1)^2}{N-1}}$	$p13 = \frac{\sum_{k=1}^K (s(k)-p12)^2}{(K-1)}$
$p3 = \left(\frac{\sum_{n=1}^N \sqrt{ x(n) }}{N}\right)^2$	$p14 = \frac{\sum_{k=1}^K (s(k)-p12)^3}{K(\sqrt{p13})^3}$
$p4 = \sqrt{\frac{\sum_{n=1}^N (x(n))^2}{N}}$	$p15 = \frac{\sum_{k=1}^K (s(k)-p12)^4}{Kp13^2}$
$p5 = \max x(n) $	$p16 = \frac{\sum_{k=1}^K f_k s(k)}{\sum_{k=1}^K s(k)}$
$p6 = \frac{\sum_{n=1}^N (x(n)-p1)^3}{(N-1)p2^3}$	$p17 = \sqrt{\frac{\sum_{k=1}^K (f_k - p16)^2 s(k)}{K}}$
$p7 = \frac{\sum_{n=1}^N (x(n)-p1)^4}{(N-1)p2^4}$	$p18 = \sqrt{\frac{\sum_{k=1}^K f_k^2 s(k)}{\sum_{k=1}^K s(k)}}$
$p8 = \frac{p5}{p4}$	$p19 = \sqrt{\frac{\sum_{k=1}^K f_k^4 s(k)}{\sum_{k=1}^K f_k^2 s(k)}}$
$p9 = \frac{p5}{p3}$	$p20 = \frac{\sum_{k=1}^K f_k^2 s(k)}{\sqrt{\sum_{k=1}^K s(k) \sum_{k=1}^K f_k^4 s(k)}}$
$p10 = \frac{p4}{\frac{1}{N} \sum_{n=1}^N x(n) }$	$p21 = \frac{p17}{p16}$
$p11 = \frac{p5}{\frac{1}{N} \sum_{n=1}^N x(n) }$	$p22 = \frac{\sum_{k=1}^K (f_k - p16)^3 s(k)}{Kp17^3}$
	$p23 = \frac{\sum_{k=1}^K (f_k - p16)^4 s(k)}{Kp17^4}$
	$p24 = \frac{\sum_{k=1}^K (f_k - p16)^{1/2} s(k)}{K \sqrt{p17}}$

Conventional parameters:

In Table 1 conventional parameters from the time and frequency domain that were calculated, are shown. Where x(n) is a signal series for n = 1, 2, . . . , N, N is the number of signal samples and s(k) is the Fourier transform for k = 1, 2, . . . , K, K is the number of spectrum lines, f_k is the frequency value of the kth spectrum line. Parameter p1 is the mean of the signal, p2 is its root mean square, p5 is obviously the absolute maximum of the signal, p4 the standard deviation, p6 and p7 the third and fourth moments whilst p8–p11 result as a combination of previous parameters all calculated by the signal in time domain. Correspondingly, p12–p24 are extracted in the frequency domain. These parameters are typical parameters in the time and in the frequency domain that can be extracted from any signal.

III. RESULT AND DISCUSSION

A. OK (Healthy) condition:

Spectral analysis:

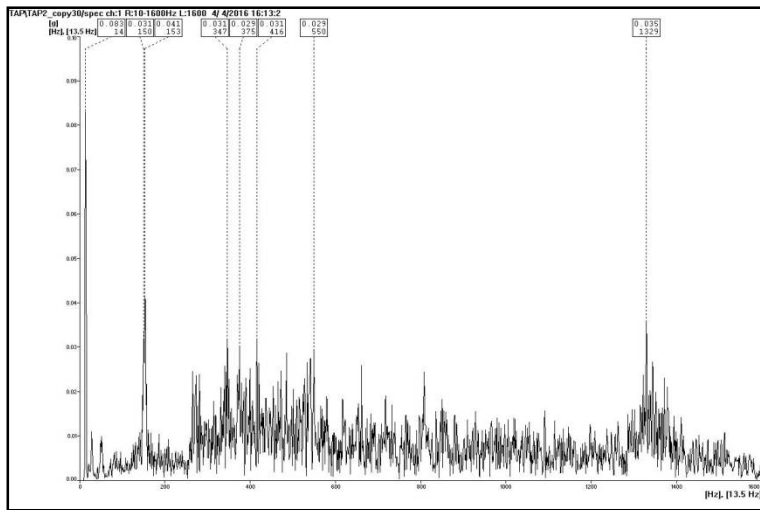


Fig. 4: Frequency Spectrum harmonic of OK condition at 1000rpm

The Fig.4 shows the frequency spectrum harmonic of OK (Healthy) condition at 1000rpm. The above graph is obtained from the FFT analyser. In this figure the top eight peaks are shown which are obtained at different frequencies.

Using Feature extraction analysis:

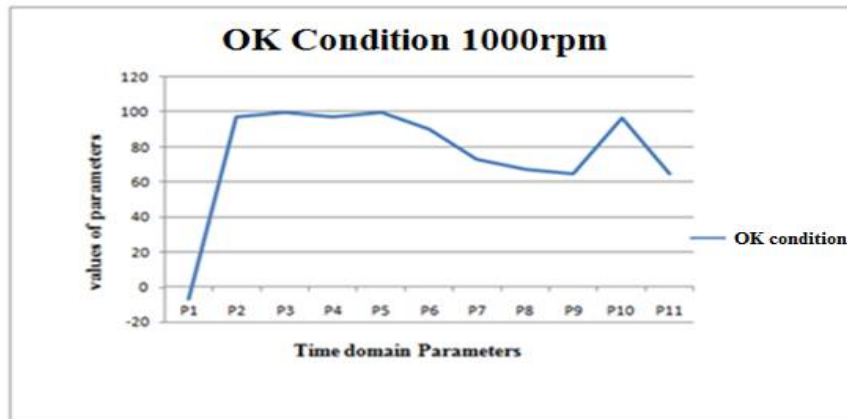


Fig. 5: Plot for OK condition Vs Time domain Parameters

The Fig.5 & Fig.6 shows comparison of vibration feature extraction time & frequency domain parameters which are calculated using signal data respective OK (Healthy) at 1000 rpm.

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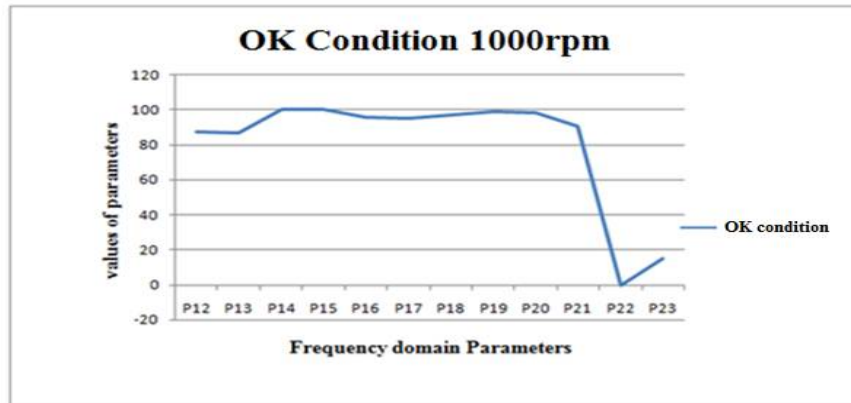


Fig. 6: Plot for OK condition Vs Frequency domain Parameters

The respective Observations are as follows:

From time domain parameter plot:

Parameters like P1 have negative value and P3 & P5 has maximum 100% value.

Parameters P6 to P9 have decreased linearly variation in value.

Parameters P9 to P10 have increased linearly variation in value.

From frequency domain parameter plot:

The parameters like P22 having lowest minimum, P14 & P15 have maximum value.

Parameters like P12 to P14 and P16 to P19 have linearly increased variation in their value.

Parameter P20 & P22 have decrease in variation in value.

B. One tooth missing (OTM) condition :

Spectral analysis:

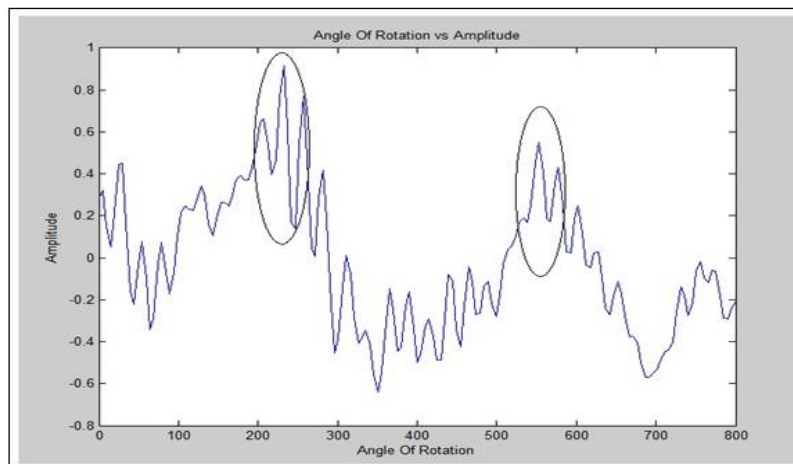


Fig. 7: Plot for one revolution of gear of OTM condition at 1000rpm

From fig.7, it is clear that the amplitude of acceleration is suddenly increased nearly 210-220° of angle of rotation of gear for one revolution, while taking the readings in OTM condition the position of missing gear tooth is nearly 220° from direction of revolution of gear. So we can conclude that the position of missing gear tooth is identified which is at 210- 220° with sudden increase in amplitude level.

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Using Feature extraction analysis:

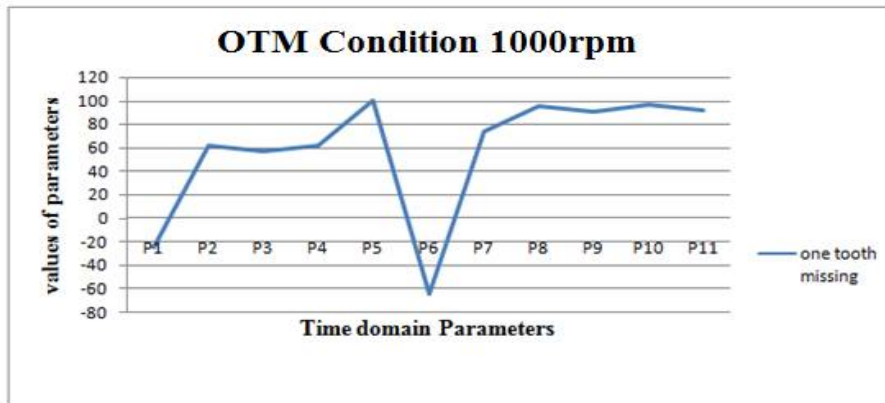


Fig. 8: Plot for OTM condition Vs Time domain Parameters

The Fig.8 & Fig.9 shows comparison of vibration feature extraction time & frequency domain parameters which are calculated using signal data respective to one tooth missing condition at 1000 rpm.

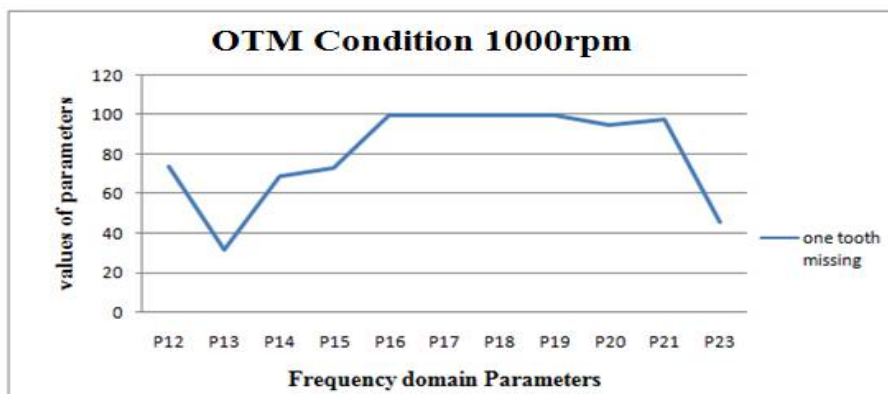


Fig. 9: Plot for OTM condition Vs Frequency domain Parameters

The respective Observations are as follows:

From time domain parameter plot:

The range of values of parameters like P1 & P6 is minimum value (negative) & P5 has maximum 100% value.

Parameters like P2 to P5 have increased linearly variation in value.

From frequency domain parameter plot:

The parameters like P16 to P19 having constant values approximately 100%

P13 to P16 have linearly increased variation in their value.

P20 to P23 have linearly decreased variation in their value.

IV. CONCLUSION

The one tooth missing (OTM) condition is detected by using statistical analysis of vibration signal. The most effective statistical parameters are P1, P2, P4, and P5. The position of one tooth missing is detected by observing the plot of one revolution of gear tooth through MATLAB program at an angle of approximately 210-220° and it again repeated after next revolution (360°). This method is effective to examine the different type of defects in gearbox system. The peaks are present at sub-harmonics and multiples of frequencies. The cause of presenting the sub harmonics & multiples of

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frequencies is due to the presence of fault in the Gearbox. This paper has used to investigate the detection of Gear fault using vibration monitoring & feature extraction parameters.

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