Condition Monitoring Technique to Investigate Gear Fault with Artificially Induced Gear Crack by using Vibration Analysis

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Abstract— **In gearboxes, gear defects and load fluctuations on the gearbox are two main causes of vibration. Because of inaccessibility of mounting of the vibration transducers, it is difficult to measure the vibrations. For investing the different types of gear faults which are artificially induced, an experimental data is collected from two stage gearbox setup with the help of FFT analyzer. The vibration analysis technique is used to detect faults in gearbox system. In vibration analysis technique gear faults are detected based on Time-Frequency analysis with the help of MATLAB software. Various types of gear defects can be artificially induced on gear tooth such as missing tooth, one corner defect, two corner defect, inadequate lubrication etc. By comparing the result of signals of healthy condition gear with defective condition through the FFT analyzer. Analysis is carried out with graphs of high frequency vibrations. With the help of MATLAB software validation of this data is successfully carried out.**

Keywords— **Gears, One Tooth Missing (OTM), Fault detection, Condition Monitoring**

I. INTRODUCTION

Gearbox is a widely used in automotive, industries and daily life applications for changing the shaft speed, the power and the torque. The transmission of the power with the help of gearbox has been used so many years ago. Depending on the design of the gearing system, gears offer many advantages to produce a high speed ratio, transmitting a high load efficiently and changing the rotation direction. Gear failure causes due to an excessive applied load, installation problems, insufficient lubrication or manufacturing errors. Gear failure is an unwanted phenomenon which causes termination of ability of the gear to perform the required task and also entail serious and costly consequences. A statistical data since from 1999 shows that 192 helicopter accidents were occurred, out of them 28 i.e. 15% were directly occurred due to the mechanical failure. Mechanical fault or failure is the most common failure occurring on the drive train of the gearbox. Since the last 20 years, many scholars and researchers have studied and concentrated on the failure and damage detection techniques in mechanical equipment. But still faults can takes place at any time on rotating machinery which causes harmful results or delay in production. By implementing an appropriate maintenance strategy, the number of failures and unplanned stoppage can be reduced.

Problem Definition: Gears are important element in a variety of industrial applications such as machine tool and gearboxes. An unexpected failure of the gear may cause significant economic losses. For this reason, fault diagnosis in gears has been subject of intensive research. Vibration signal analysis has been widely used in the fault detection of rotation machinery. The vibration signal of a gearbox carries the signature of the fault in the gears, and early fault detection of the gearbox is possible by analyzing the vibration signal using different signal processing techniques.

Objectives of Project: To test defect free gearbox for obtaining vibration characteristics at different speeds and loads. Testing of defective gearbox for obtaining vibration parameters such as FFT spectrum, kurtosis, crest factor, time domain & frequency domain feature extraction parameters and comparison of above parameters for defective and defect free Gear by using MATLAB program.

II. LITERATURE REVIEW

M. Amarnath et. al. (2014) "Local fault detection in helical gears via vibration and acoustic signals using EMD based statistical parameter analysis" This paper depicts the execution of Empirical Mode Decomposition (EMD) technique for observing simulated faults utilizing vibration and acoustic signals as a part of two stage helical gearbox. By EMD technique, a complicated signal can be converted into various Intrinsic Mode Functions (IMF). Vibration and acoustics signs are deteriorated to remove higher order measurable parameters. Results exhibit the adequacy of EMD based measurable parameters to analyze seriousness of local faults on gear tooth profile. The values of Kurtosis from EMD and that got from vibration and acoustic sign are contrasted with exhibit the prevalence of EMD based method. [1][3]

T.H. Loutas et. al. (2009) "Condition monitoring of a single-stage gearbox with artificially induced gear cracks." A single stage gearbox was used keeping in mind, the end goal to concentrate on the improvement of artificially induced crack on the gear. The test setup was run for multi-hour and various recordings were obtained by utilizing vibration monitoring and

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acoustic emission. The principle objective of the study was to extract a set of parameters and check their diagnostic behavior for further health monitoring scheme. The distinction in the parameters development of each NDT strategy are talked about and the prevalence of AE over vibration recording for early analysis of regular wear in gear system is concluded.[5][6]

G. Ibrahim et. al. (2013), "Adaptive filtering based system for extracting gearbox condition feature from the measured vibrations." This article gives a novel method for extracting gearbox faults using adaptive separating technique for upgrading meshing frequency sidebands, condition features. An altered Least Mean Square (LMS) algorithm is created and validated using single accelerometer instead of two accelerometers which used in traditional principle signals and the desired signals are artificially produced from the gear meshing frequencies and measured shaft speed. The proposed plan is applied to a signal reproduced from gearbox frequencies with various values of step size. Results gives confirmation that, 10^{-5} step size constantly creates more exact results and there has been a considerable change in signature clarity which make meshing frequency sidebands more recognizable.[2]

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.[8,9]

III. CONDITION MONITORING

Gears are frequently basic and vital components in the gearbox requiring the use of condition monitoring techniques. The level of wear debris and load to which they are subjected to typical working conditions that implies they are often subjected to inauspicious failure. 50-70% of gearbox leads to fail due to the defects which produce in the gears. To discover the state of these gears, parameters like oil contamination, temperature, vibration, noise, wear debris etc. are used.

Table 1 Available Condition monitoring techniques

A. Acoustic Monitoring	**B. Vibration Monitoring**	**C. Wear Debris Analysis**	**D. Visual Inspection**
Microphone	Overall monitor	Ferrography	Radiography
Spectral analysis	Spectral analysis	Inductive sensors	Eddy current
FFT technique	Shock pulse monitoring	Capacitive sensors	Ultrasonic
	Signal averaging	Spectrographs	
	FFT technique		

Condition monitoring of a gearbox system is of extensive significance to industry since an early identification of faults in them can avoid failures in the machines. The technique of machine condition monitoring is to screen the condition of machine and to recognize any weakening in condition, to decide the reason for failure. The outcome is the amplification of machine accessibility and most extreme usage of the machine components (Bearing, Gears etc.) In condition monitoring of machine, vibration analysis technique is commonly used.

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 versus hardware that has been utilized will give the data and settle on a choice, whether the upkeep 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. Defect analysis is performed regularly in the accompanying stages: data acquisition, feature extraction, and defect detection and identification. Valuable feature extraction procedures are exceptionally basic for the accomplishment of defect diagnosis.

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.[4] 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 [4].

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 induction motor, a two stage spur gearbox, shaft couplings and load device (rope brake dynamometer). The gearbox comprises of two stage 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 in Table 2 & 3

Table 2 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 3 Specifications of Gears

	Stage 1		Stage 2	
Particulars	Gear	Pinion	Gear	Pinion
Type	Spur		Spur	
Tooth Profile	20°		20°	
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	

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.

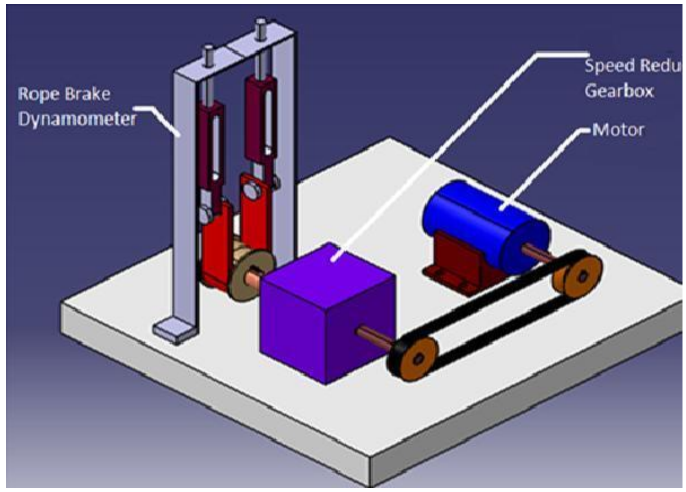

Fig. 1.Experimental Model of Set Up

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. Magnetic base accelerometer is located 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- one tooth missing, two corner defect, one corner defect and wear formation. Out of which for analysis purpose, we considered one tooth missing fault and wear formation. Refer Fig. 2.

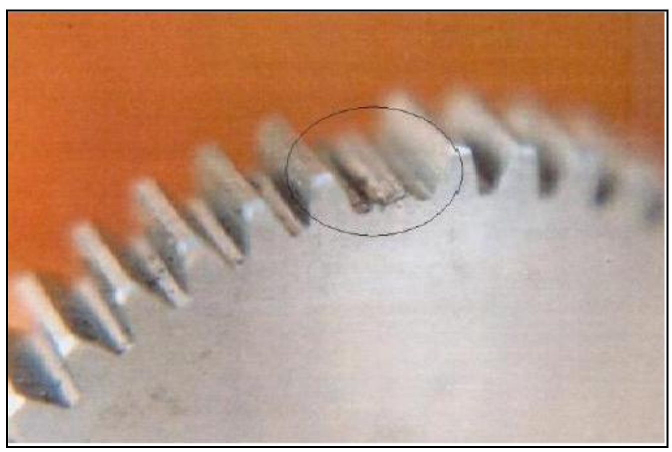

Fig. 2. One Tooth Missing (OTM) Defect

C. PROCESSING OF SIGNAL

Signal processing is carried out in MATLAB program by .csv and.wav files as 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 (p1, p2, p3…etc) along with parameters like kurtosis, standard deviation, crest factor and RMS are also determined [7] [8]. The MATLAB program is use to get different waveform like frequency domain and time domain.

IV. RESULTS AND DISCUSSION

A. *Surface Crack and One Tooth Missing [OTM] Condition*

1) Using Spectral Analysis

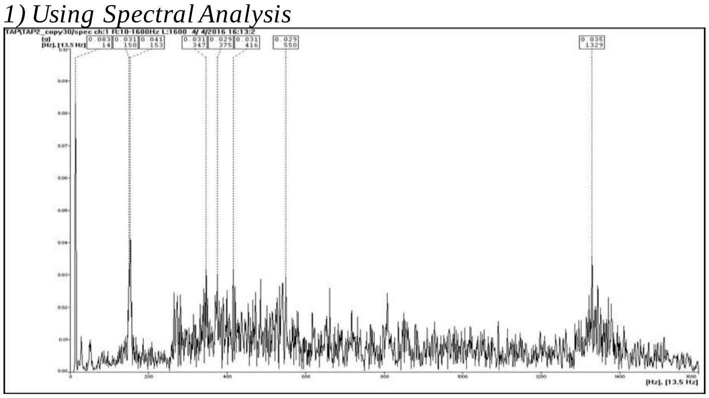

Fig. 3 Healthy Condition at 600 rpm in FFT

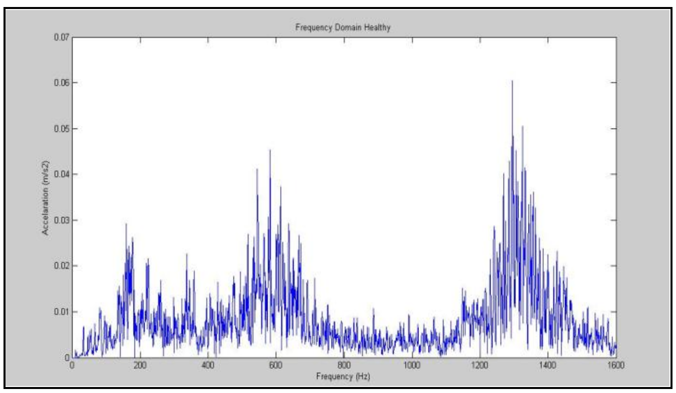

Fig. 4 Healthy Condition at 600 rpm in MATLAB

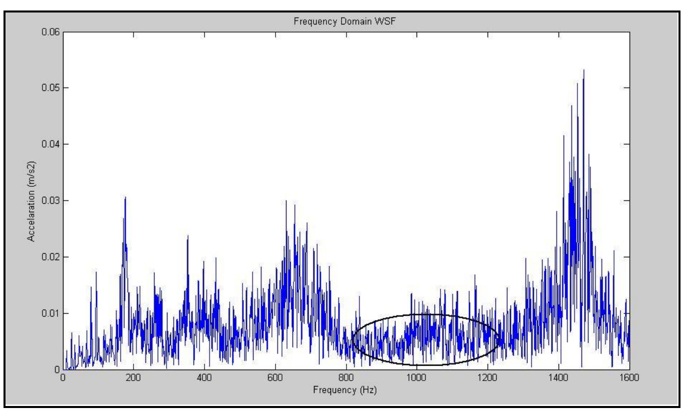

Fig. 5 Surface Crack at 600 rpm in MATLAB

Fig. 3, 4 and Fig. 5 shows the frequency domain characteristics for healthy condition gear and artificially induced surface crack on gear respectively. From Fig. 4 and Fig. 5, it can be observed that, Frequency of vibration of for the faulty gear i.e. surface crack induced on gear increases abruptly in the region of 800Hz to 1200Hz. Hence we can observe that there is a fault in gear where the frequency of the vibration changes drastically.

From Fig.6, 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°.

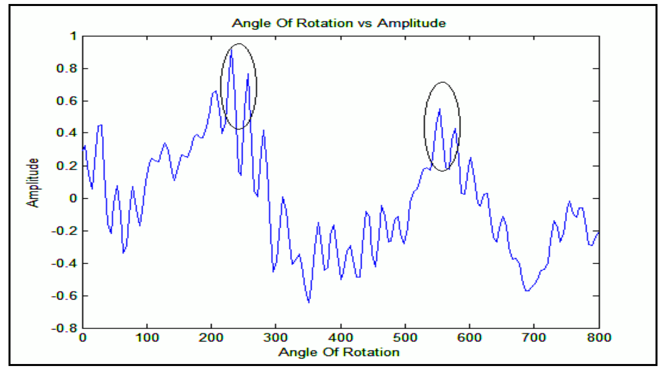

Fig. 6 Missing Tooth Condition (1000rpm) in MATLAB

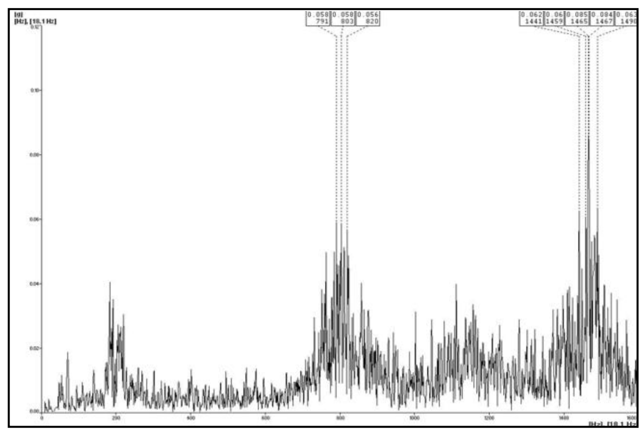

Fig. 7 Missing Tooth Condition (1000rpm) in FFT

B. *Using Time Domain Analysis*

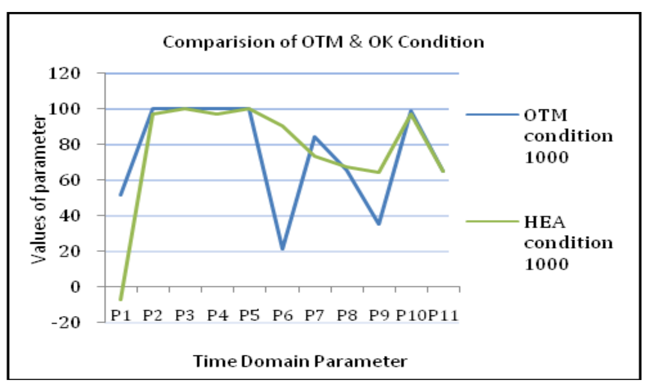

Fig. 8 Comparison of OTM & HEA Condition Vs Time Domain Parameters at 1000 rpm

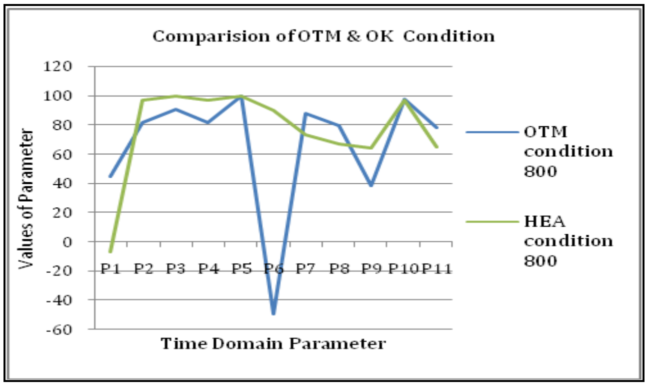

Fig. 9 Comparison of OTM & HEA Condition Vs Time Domain Parameters at 800 rpm

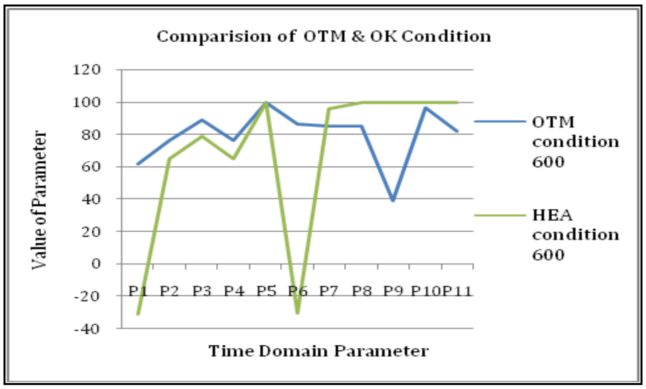

Fig. 10 Comparison of OTM & HEA Condition Vs Time Domain Parameters at 600 rpm

The above graphs show the comparison of time domain parameters (P1 to P11) in Fig. 8, 9 and 10. 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:

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 and P9 Parameters have maximum value in HEA (Healthy) condition as compared to OTM (One Tooth Missing) condition.

C. *Using Frequency Domain analysis*

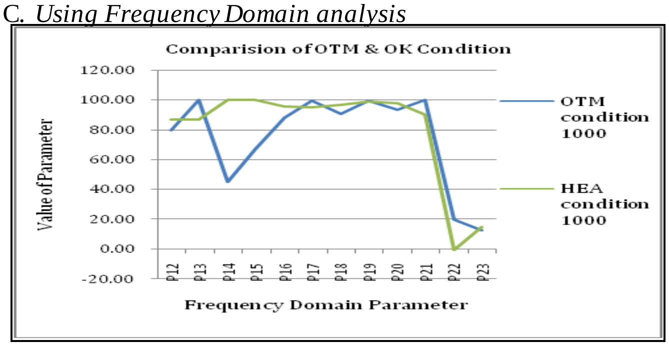

Fig. 11 Comparison of OTM & HEA Condition Vs Frequency Domain Parameters at 1000 rpm

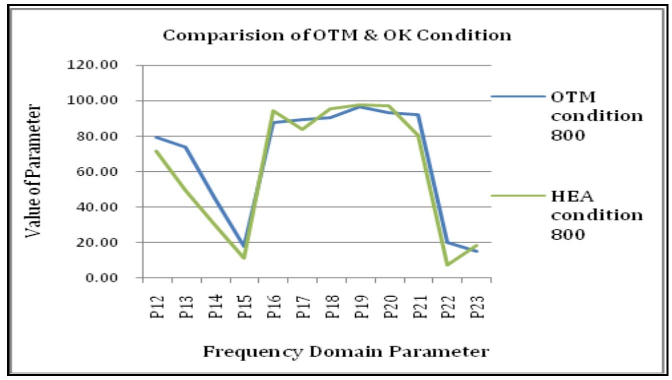

Fig. 12 Comparison of OTM & HEA Condition Vs Frequency Domain Parameters at 800 rpm

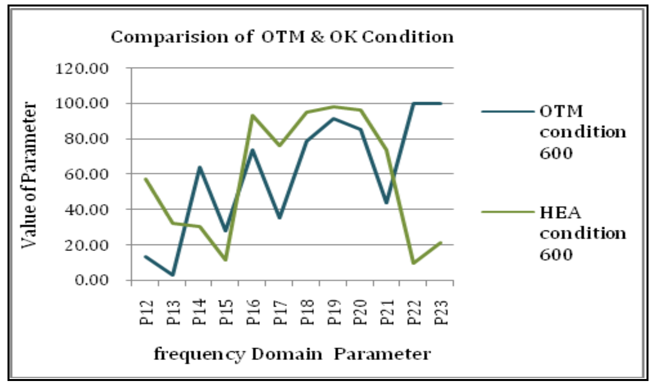

Fig. 13 Comparison of OTM & HEA Condition Vs Frequency Domain Parameters at 600 rpm

The above graphs show comparison of frequency domain parameters (P12 to P24) in Fig. 11, 12 and 13. These parameters are calculated by using signal data with respect to one tooth missing condition at 600 rpm, 800 rpm and 1000 rpm. The corresponding Observations are as follows:

1. The parameters like P15 and 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 and 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 Fig. 6, 7 and 8.
2) Frequency domain parameter like P15, P16, P18, P19, P2O, and P22 can also use to detect missing of tooth in gear.
3) 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°.
4) This paper has examined the Gear fault detection using feature extraction parameters i.e. time & frequency domain parameter and vibration monitoring.

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