

# **A Review on Fault Detection of Gearbox by using Vibration Analysis**

<sup>1</sup>Vikram A. Jagtap, <sup>2</sup>Prof. Pavankumar R. Sonawane.

<sup>#1</sup>Research Scholar, Department of Mechanical Engineering, D Y Patil Institute of Engg.& Technology, Ambi, Pune.  
Maharashtra, India

<sup>#2</sup>Assistant Professor, Department of Mechanical Engineering, DY Patil Institute of Engg.& Technology,  
Ambi, Pune, Maharashtra, India.

**ABSTRACT:** A gearbox is a core component in rotating machinery and has been widely employed in various industrial equipment. An unexpected failure of the gearbox may cause significant economic losses. It is, therefore, very important to find early fault symptoms from gearboxes. There are various methods to detect faults in gearbox. Vibration signal analysis is the main technique for monitoring the condition and detecting faults in a gearbox. Vibration analysis has been used as a predictive maintenance procedure and as a support for machinery maintenance decisions. By employing appropriate signal processing methods, changes in vibration signals caused by faults can be detected to aid in evaluating the gearbox's health status. By measuring and analysing the machine's vibration, it is possible to determine both the nature and severity of the defect, and hence predict the machine's failure. 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 analysing the vibration signal using different signal processing techniques. This paper gives a brief review on various techniques used for analysing the faults of gearbox based on vibration analysis method with small insight on new approach used for diagnosis of gearbox such as Artificial Neural Network, fuzzy sets and some emerging technology in gear fault analysis.

**KEYWORDS:** Vibration, Gearbox, Fault diagnosis, Vibration signature, Vibration measurement techniques

## **I. INTRODUCTION**

All machines with moving parts give rise to sound and vibration. Each machine has a specific vibration signature related to the construction and the state of the machine. If the state of the machine changes the vibration signature will also change. A change in the vibration signature can be used to detect incipient defects before they become critical. This is the basics of many condition monitoring methods. Condition monitoring can save money through increased maintenance efficiency and by reducing the risk of serious accidents by preventing breakdowns. The use of vibration analysis as one of the fundamental tools for condition monitoring has been developed extensively over a period of approximately 35 years. With the parallel developments in electronic equipment, transducers, computers and software nowadays machine supervision is almost completely automated. In the present work the authors present a review of a variety of diagnosis techniques for gearbox fault identification with particular regard to vibration analysis. The vibration techniques were developed with two main purposes. The first purpose is to separate the gearbox related signal from other components and to minimize the noise that may mask the gearbox signal, especially in the early stages of the fault. The second purpose is to identify the status of the gearbox, to distinguish the good and the faulty gear and to indicate the defective components. Examples of widely used techniques for gearbox are such as Waveform analysis, Time-Frequency analysis, Faster Fourier Transform (FFT), Spectral analysis, Order analysis, Time Synchronous Average, and probability density moments. These vibration based diagnosis techniques has been the most popular monitoring technique because of ease of measurement. Vibration analysis was used former mainly to determine faults

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Vol. 6, Issue 7, July 2017

and critical operation conditions. Nowadays the demands for condition monitoring and vibration analysis are no more limited trying to minimize the consequences of machine failures, but to utilize existing resources more effectively.

## 1. Vibration Analysis for Fault Detection and Diagnosis

A measurement signal acquired from a machine in working environment will often contain effects from several different components with noise. One major challenge of condition monitoring is to identify and choose the part of the signal that can be related to the condition of the monitored component. Most modern techniques for gear diagnostics are recognized on the analysis of vibration signals collected from the gearbox casing. The main target is to detect the presence and the type of fault at start of development and to monitor its progress, in order to guess the machine's residual life and choose a suitable plan of maintenance. It is well known that the most important components in gear vibration are the gear meshing frequency and harmonics, accomplished with sidebands due to modulation. The increment in the number and amplitude of sidebands can indicate a fault in gearbox. In Gears, vibration analysis can detect tooth meshing faults, misalignment, cracked and/or worn teeth, eccentric gear etc. faults. Vibration analysis can detect Unbalance, bent shaft, misalignment, eccentric journals, loose parts, rubs, crucial speed, cracked shaft etc. faults of a rotor and shaft. Pitting of race and ball/roller, spalling etc. faults of rolling element bearing can be detected by using vibration analysis techniques effectively.

## II. REVIEW

Numbers of papers are presented on fault detection of gearbox by using various vibration analysis methods. Here we are going to review some of techniques used to model faults of gearbox using vibration analysis method. These techniques are mainly divided into three areas as Time domain approach, Frequency domain approach and Time-Frequency domain approach.

[1] J. Antoni, R. B. Randall (2002) deals with the vibration-based diagnosis of rolling element bearings with existence of strong intrusive gear signals, such as is typical of helicopter gearboxes. The key idea to detect gear frequency is that gear signals are purely periodic, whereas bearing signals occurs with some randomness and is close to cyclostationary, i.e. with a periodic bivariate autocorrelation function. They found that for localized faults pseudo cyclostationary vibration signal are produced which can be considered as cyclostationary in first approximation. And for Distributed faults they propose simple spectral analysis. They check the effectiveness of this method on experimental and actual vibration signal.

[2] S.J. Loutridis (2004) present a method for monitoring the detection of gear faults based on the empirical mode decomposition scheme. A gear pair with a tooth root crack was modeled theoretically. Experimental vibration signals from an instrument were decomposed into intrinsic mode functions (IMF). An empirical law relating the energy content of the intrinsic modes to the crack size was developed. The modal energy associated with the deterioration in gear condition can be utilized for system failure estimate. In addition, it is shown that the instantaneous frequency of the vibration signal is a sensitive sign for to detect the presence of damage in the gear pair.

[3] Xianfeng Fan et al (2005) combines Hilbert transform and wavelet packet transform. Both virtual signals and real vibration signals collected from a gearbox dynamics simulator are used to verify the proposed method. Investigated outcomes show that the proposed method is effective to select particular modulating signal and help to detect the early gear fault. In addition, it has the capability to analyze non-stationary signals. Compared with wavelet packet transform only, it has more benefits such as accuracy, efficiency, and easy faults detection by visual inspection of vibration spectra.

[4] Z.K. Peng et al (2005) present Improved Hilbert-Huang transform (HHT). In the improved HHT, the wavelet packet transform is used to preprocess vibration signal for decomposing it into a set of narrow band signals at first, and then the EMD is applied on those obtained narrow band signals and some IMFs will be generated, finally an effective IMF selection method is used to select the useful IMFs and eliminate the unnecessary IMFs. They found that the improved HHT has better resolution both in time domain and in frequency domain than the scalogram. The improved HHT has better calculating efficiency than scalogram. The HHT spectrum also has one unresolved and maybe unavoidable deficit as ripple phenomenon in its expected frequency which would lead to wrong analysis.

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Vol. 6, Issue 7, July 2017

- [5] DejeTu et al (2005) proposed a method for the fault diagnosis of roller bearing based on Empirical mode decomposition and Hilbert transform. The orthogonal wavelet sources are used to transform vibration signals of a roller bearing into time-scale illustration. Then, an envelope signal can be obtained by envelope spectrum analysis of wavelet coefficients of high scales. By applying EMD method and Hilbert transform to the envelope signal, we can get the local Hilbert marginal spectrum from which the faults in a roller bearing can be detected and fault patterns can be identified. Practical vibration signals measured from roller bearings with out-race faults or inner-race faults are analyzed by them. The results show that the method given by in this paper is superior to the old envelope spectrum method in detecting the fault characteristics of roller bearings.
- [6] B. Liu et al (2006) present a paper in which they apply empirical mode decomposition (EMD) and Hilbert spectrum method to vibration signal analysis for localized gearbox fault diagnosis. They use B-spline EMD as a filter bank to understand mechanisms behind EMD. After that they investigate the effectiveness of the original and the B-spline EMD with their corresponding Hilbert spectrum in the fault detection. Vibration signals collected from an automobile gearbox with an initial tooth crack are used in the examination. The results show that the EMD processes and the Hilbert spectrum perform superbly to found defect and is more effective than the frequently used continuous wavelet transform to detect fault with help of the vibration signatures of gearbox.
- [7] Yimin Zhan et al (2006) gives a robust model-based technique for the detection and diagnosis of gear faults under varying load conditions using the gear motion residual signal. The gear motion residual signal usually shows evidence of faults earlier and more clearly than the TSA signal. They proposed a method in which the load is continuously varied. By using Auto Regression model on residual signal it can indicate stable and more reliable measure of state of gear of interest under varying load conditions when compared to other techniques.
- [8] EnayetB. Halim et al (2008) proposes a new technique as time domain averaging across all scale, which combines the time synchronous average and wavelet transformation with each other to extract the periodic waveforms at different scales from noisy vibration signals. The technique effectively cleans up noise and detects both local and distributed faults at the same time. The presence of a fault in any gear of the gearbox gives rise to a peak in the plot of the TDAS. A missing tooth creates a large peak and a chipped tooth creates a peak with a parallel side peak at the meshing frequency. Instantaneous multiple faults in the gearbox can be detected by looking at the peaks of the plot of TDAS. A pilot plant case study is presented to validate the efficacy of the proposed technique.
- [9] Ming Yang et al (2010) present an ARX model-based gearbox fault detection and localization under varying load conditions. Firstly they calculate residual signal using an autoregressive model with variables (ARX) fitted to the timesynchronously averaged (TSA) vibration data and filtered TSA envelopes at healthy condition of gearbox operated under several load conditions. The gear of interest is separated into several sections so that each section includes the same number of adjacent teeth. Then, the fault detection and localization indicator is calculated by applying F-test to the residual signal of the ARX model. The proposed fault detection scheme indicates gear fault occurrences as well as location of faults i.e. section of the gear. Hence it is very suitable to use this technique for online condition monitoring.
- [10] Xiyang Wang et al (2010) discussed a wavelet approach to fault diagnosis of a gearbox under varying load conditions. As varying load can make changes in a measured gearbox vibration signal it is necessary to develop a technique which provide accurate condition monitoring of gearbox under fluctuating load conditions. They presents a method to detect gear fault based on complex Morlet continuous wavelet transform under varying load condition. Gear motion residual signal usually represents the withdrawal of time synchronously averaged signal from the average tooth-meshing vibration. This is analyzed as source data due to its inferior sensitiveness to the varying load condition. A fault growth factor based on the amplitude of wavelet transform is suggested to evaluate gear fault progression. They found that this parameter is insensitive to varying load and can correctly indicate early gear fault. The efficiency of the proposed fault indicator is validated using a full lifetime vibration data history obtained under sinusoidal varying load.
- [11] FaragK.Omaret al (2011) proposed dynamic wavelet-based tool for gearbox diagnosis in noisy environment. It utilizes a windowing process at time of analysis of gearbox vibration signals in the wavelet domain. The gear vibration signal is processed by using dynamic Kaiser's window of varying parameters. The window size, shape, and sliding rate are revised due to increasing the similarity between the non-stationary vibration signal and the designated mother wavelet. The window parameters are uninterruptedly revised until they offer maximum wavelet coefficients restricted to the defected tooth. They applied this technique on laboratory data corrupted with high noise level. This technique has shown accurate results in detecting and pinpointing gear tooth fracture with altered damage severity.

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Vol. 6, Issue 7, July 2017

[12] David G. Lewicki et al (2011) gives insight to Planetary Gearbox Fault Detection Using Vibration Separation Techniques supported by NASA. In this paper total nine condition indicators are used to determine fault present in planetary gearbox of helicopter. They are as RMS, crest factor, energy ratio, FM0, kurtosis, energy operator, FM4, M6A and M8A. They found that condition indicator M8A performed the best during their study. The fault in sun and planet gear is detectable by using vibration analysis techniques. Enveloping of signal is an effective method for detection of planet bearing inner and outer-race spalling fault. They found that greater change in vibration was noticed when crack is being closed rather than it open up during meshing.

[13] M. Loksha (2011) presents Fault diagnosis in gear using wavelet envelope power spectrum. The use of wavelet analysis has proven to be efficient to detect faults in vibration signals with no stationary, transient characteristics/ components. An experimental data set is used to compare the diagnostic capability of the fast Fourier transform power spectrum to the wavelet envelope power spectrum as respectively computed using Laplace and Morlet wavelet functions. The gear testing apparatus was used for experimental studies to obtain the vibration signal from a healthy gear and a faulty gear. The vibration signal processing techniques using FFT, Morlet wavelet enveloped power spectrum and Laplace wavelet enveloped power spectrum are implemented and their results are compared for various stages of induced gear fault. The proposed application shows the prominence of Morlet wavelet and Laplace wavelet based enveloped power spectrum for identification of fault in gear by comparing the significant increase in vibration amplitude at GMF and their 1xRPM of side bands compared to FFT power spectrum.

[14] G Diwakar et al (2012) analyze gear faults by using FFT Analyzer. The vibration signals of gearbox are detected and processed using FFT analyzer. They detect the fault in Gearbox by the interpretation of vibration data and spectrums. The vibration signature shows the fault in Gearbox when Gearbox is operated at different Gears on full load condition. They found that vibration analysis provides a highly sensitive, selective, and effective technique for online monitoring of a wide variety of heavy industrial machinery. The peaks are present at sub-harmonics and multiples of frequencies. The cause of presenting the sub harmonics & multiples of frequencies is due to the presence of fault in the Gearbox.

[15] Prashant Bagde et al (2013) studied various faults arise in gearbox and the corresponding change of vibration signature. They found that the condition of the tested gearbox is very well represented by the RMS value of the vibration signal. Behaviour of the RMS, peak and crest factor value is described in this paper. The energy ratio has a steady trend except at the start of the test. The peak value has a similar trend as the RMS value. The trend of the crest factor depends on the trends of the RMS and peak values. FM0 follows the trend of the crest factor. The trends of FM4, NA4 and NB4 are similar, and reflect the very fine wear of the teeth. At about 60% of the test FM4, NA4 and NB4 rapidly increase in value, but the gearing does not show abnormal wear.

[16] Songpon Klinchaeam (2014) presents a condition monitoring technique of a spur gear fault detection using vibration signal analysis based on time domain. Vibration signals were acquired from gearboxes and used to simulate various faults on spur gear tooth. In this study, vibration signals were applied to monitor a normal and various fault conditions of a spur gear such as normal, scuffing defect, crack defect and broken tooth. The statistical parameters of vibration signal were used to compare and evaluate the value of fault condition. This technique can be applied to set alarm limit of the signal condition based on statistical parameter such as variance, kurtosis, and rms and crest factor. These parameters can be used to set as a boundary decision of signal condition. From the results, the vibration signal analysis with single statistical parameter is unclear to predict fault of the spur gears. The using at least two statistical parameters can be clearly used to separate in every case of fault detection. The boundary decision of statistical parameter with the 99.7% certainty ( $\pm 3\sigma$ ) from 300 referenced dataset and detected the testing condition with 99.7% ( $\pm 3\sigma$ ) accuracy and had an error of less than 0.3 % using 50 testing dataset. This work has demonstrated through a range of experimental results that vibration signal analysis technique has a potential for investigating the behavior of gearbox rotation. The vibration signal of a spur gear damage could use time-domain signal analysis with Boundary Decision (BD) to clearly 4 classify the fault pattern signal time-domain as well as can be used to separate the gearbox fault condition. This technique can be used as a tool to detect for fault detection. However, the knowledge of rotating machine processes and signal processing techniques is necessary for statistical analysis based on the co-parameter of a feature vector that was used to analysis or to classify using by boundary decision analysis. This method could be used to separate the fault conditions without the knowledge of the gearbox operation in order to set up the alarm limit of the



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Vol. 6, Issue 7, July 2017

condition monitoring system. For future work, it is necessary to use advanced signal processing technique to improve accuracy of the gearboxes state monitoring and to improve vibration monitoring technique for reliability systems.

[17] L.S.Dhamande (2014) presents paper on gear fault detection in gearbox using vibration analysis. In gearboxes, load fluctuations on the gearbox and gear defects are two major sources of vibration. Further, at times, measurement of vibration in the gearbox is not easy because of the inaccessibility in mounting the vibration transducers. For detecting different type of gear tooth faults an experimental data is taken from single stage gearbox set up with help of FFT analyzer. Vibration analysis techniques are used for detection of fault in gear system, fluctuation in gear load. A method for detecting the evolution of gear faults based on time- frequency analysis through MATLAB. The various types of defects can be created on gear tooth such as one corner defect, two corner defect, three corner defects, Missing tooth, inadequate lubrication, wear formation etc. By comparing Signals of defective condition with healthy (ok) condition through FFT analyser in which, analysis is carried out with the signal to trace the sidebands of the high frequencies of vibration. The validation is done successfully by taking input signal from FFT analyser to MATLAB program. It is for calculating effective statistical parameters in defective condition for time & frequency domain analysis. The actual position in angle of rotation for one tooth missing in gearbox is also investigated by using MATLAB program. It is also helpful tool for health monitoring of gears in different conditions.

[18] T Praveenkumar et al (2014) addresses the use of vibration signal for automatic fault detection of gearbox. The Performance of the fault detection system using vibration signals is discussed. In their studies, they examine good gears and face wear gears to collect vibration signals for good and faulty conditions of the gearbox. Two different speeds and loading conditions are used to test each gear. The statistical parameters such as Mean, Median, Mode, RMS, Kurtosis, Skewness, variance and standard deviation are calculated from the measured vibration signals. These parameters are used as an input to the support vector machine (SVM) for fault detection. Support Vector Machine shows superior classification capability to identify various faults in the gearbox and it can be used to automate fault diagnosis system.

[19] Shashikant Shukla et al (2014) deals with fault detection of two stages spur gearbox having tooth breakage and improper chamfering fault in the gear, using time domain techniques with the use of MATLAB. Acquired data is analyzed to find out various statistical parameters like peak value, crest factor, RMS, kurtosis. Healthy and breakage gears are compared using statistical parameters. All parameters have greater values in Tooth breakage gear than healthy gear. Faulty gear has large kurtosis value as compared to healthy gear. All parameters increase with increase in speed in faulty gear but in healthy gear the values are almost constant. In improper chamfering gear all the time domain values lie between Healthy gear and faulty gear.

[20] ZhiQiang Chen et al (2015) presents an application of convolutional neural network (CNN) used for fault detection and classification in gearboxes. They consider various combinations of condition monitoring techniques based on some basic fault conditions. Vibration signals are preprocessed using indices from the time domain signal such as standard deviation, skewness, and kurtosis. The spectrum obtained with FFT is divided into multiple bands in the frequency domain, and the root mean square (RMS) value is calculated so the energy preserves its shape at the spectrum peaks. The achieved accuracy indicates that the suggested approach is highly reliable and relevant in fault diagnosis of industrial reciprocating machinery in comparing with other algorithms.

[21] Manoj Kumar Dwivedi (2015) presents the comparative analysis of healthy and cracked spur gear using vibration signal in single stage gear box. In gearbox, load fluctuations on the gearbox and gear defects are two major problem of vibration. This paper deals with the analysis of a healthy gear and faulty spur gearbox having crack defect on multiple teeth at different angle on driving gear using frequency domain technique through MATLAB software. The vibration signals are captured from the experiments and the burst in the vibration signal is focused in the analysis and the frequency of the faulty gear is found out. The analyses are done on gear under varying speeds at different loading conditions.

[22] Baquer Mohiuddin, Dr.S.B. Kivade (2016) discover the new method for damage identification and vibration analysis technique for gear box. Gear pairs in gearboxes normally generate vibration and corresponding vibration signal could be used as reference characteristics when the gear is in good mechanical condition. If defects occur to one of the gears during operation, the faulty gearbox would result in serious damage. Changes in vibration signals are often an indication that the gear pair meshing condition is changing. Measuring vibration gearbox with the help of accelerometer mounting on the gearbox housing is one of the best methods for gear pair damage assessment. Therefore, condition monitoring of the gearbox system during its operation is crucial to prevent the system from malfunction that

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Vol. 6, Issue 7, July 2017

could cause damage or entire system shutdown. Up to now condition monitoring and damage identification of industrial gearboxes has received significant attention by researchers engaged in multidisciplinary activities. The rapid progress in materials technology, intelligent sensor technology, signal processing and information technologies brings new solutions to solve a variety of problems associated with failures of industrial gearboxes in a real operational environment accurately and efficiently. Many investigations have been carried out to monitor and assess of industrial gearboxes using different techniques. These methods are well-established for industrial practices and among them vibration signal processing technique is well known. However, since the vibration signals measured from gearboxes are non-stationary and transient in nature, when damage occurs it is even more interesting to carry out investigation. All those technique have some limitations and cannot be applied in all conditions, i.e. some types of failure cannot be detected by simple vibration methods. Hence it is more desirable to investigate possibilities of some of those methods. The simple spectral analysis is generally unable to detect gear damage at an early stage; for this reason, many researchers have proposed the application of other vibration assessment techniques for the early detection of damage symptoms. The aim of this research, on the basis of experimental results is to evaluate and compare detection and diagnostic capabilities of some of vibration signal processing techniques.

[23] Vijay Kumar Karma (2016) deals with study of improper chamfering and pitting defects of spur gear faults using frequency domain technique. Spur Gears are the most widely used power transmission elements in various industries and other major industries. It is necessary to have the gears in good conditions so that the machinery runs in good conditions i.e. the gears should be free from any defects. The fault detections become important tools to diagnose the faults. There are various techniques which are used for this purpose. Vibrations analysis, Acoustic Signal analysis, Wear debris analysis etc. are the methods employed to know the health of the gears. In this paper a study is done to analyse the gear faults using frequency domain technique of vibration signals obtained from spur gear in a two stage spur gear box setup. Fast Fourier Transformation is a very versatile technique to determine the frequency contents of a signal. From these frequency content the faults can be predicted. The presence of tooth faults such as improper chamfering and pitting in any gear gives rise to peaks and generates sidebands. Thus by using FFT technique it can be predicted that the gear has some fault but the severity cannot be determined.

[24] Amar Pawar (2016) presents the fault detection technique in two stage helical gear box. 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 behavior 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.

## III. CONCLUSION

Time-frequency domain average technique (TSA) successfully removes the noise from the signal and captures the dynamics of one period of the signals. Wavelet Transform shows accurate result in detecting and localizing gear tooth fracture with different damage severity. Time domain techniques for vibration signal analysis such as waveform generation, indices (RMS value, peak level value and crest factor) and complete vibration level do not provide any diagnostic evidence under varying load condition. In frequency domain, FFT was able to show the whims at fault characteristics frequencies and its multiple frequencies but other peaks are also presents due to signal modulation effect. By this technique identification of fault categories is difficult. Support Vector Machine shows better classification ability to detect various faults in the gearbox and it can be used for automatic fault diagnosis. Convolution Neural Network could lower cost of maintenance and guarantying a continuous production system, and also it can be used to online diagnosis of process.

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Vol. 6, Issue 7, July 2017

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