wjert, 2019, Vol. 5, Issue 2, 274-281. *Review Article* ISSN 2454-695X

World Journal of Engineering Research and Technology
WJERT
www.wjert.org SJIF Impact Factor: 5.218

# A REVIEW OF CONDITION MONITORING AND FAULT DIAGNOSIS OF GEARS

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**Article Received on 02/01/2019** **Article Revised on 23/01/2019** **Article Accepted on 13/02/2019**

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## ABSTRACT

A review of condition monitoring and fault diagnosis of gears is presented in this paper. Condition Monitoring and fault diagnosis of gears has emerged as a core research area in the past few decades Periodic checks to avoid uneven tragedy is the main advantage of condition maintenance. Different types of condition monitoring techniques such as using condition indicators have been covered in this paper. A detailed study on different feature extraction methods for gear fault diagnosis using fault feature extraction have been discussed here. Different methods of detection of defects in gears like cepstrum analysis for gearbox diagnosis have also been included.

**KEYWORDS:** Cepstrum analysis, Condition monitoring, Condition indicators, Fault Diagnosis, Fault feature extraction.

## INTRODUCTION

Huge amount of research has been carried out into the condition monitoring of gearboxes, but the study of gearbox monitoring under different operational conditions like different loads and speed has not been done in details. Most of the research investigates the fault diagnosis at constant load and speed. Depending on the type of machine, its typical malfunctions, the bearing types employed, rotational speed and other factors, different diagnostic tools such as the examination of the time domain signal along with other information from the process such as load, bearing temperatures, flow rates, valve positions, and pressures to provide accurate diagnosis.

Machine Condition Monitoring helps ensure the reliability and low cost operation. Condition Monitoring can provide early detection of machine faults so that appropriate action can be taken before that fault causes breakdown and possibly, a catastrophic failure. Investigating gear damages using vibration signal is a subject of a high interest, because gears vibrational signals are complex and difficult to understand. Investigating gear damages using vibration signal is a subject of high interest. Vibration signals from gears are complex and difficult to understand. The use of vibration analysis methods for condition monitoring can be further classified into time domain and frequency domain methods. Time domain methods use statistical analysis techniques on direct or filtered time signals to detect parametric or pattern changes as transmission components wear. Statistical methods such as standard deviation and kurtosis are used to qualify general wear from tooth specific damage. The one-shot techniques include time-domain statistics such as kurtosis, visual analysis of the time domain signal looking for periodic and transient features as well as the probability density distribution. When a defect in one surface of a bearing strikes a mating surface an impulse is produced which excites resonances in the system. For a constant rotational speed, these pulses are generated periodically and the frequency of pulse generation is called the characteristic defect frequency, can be determined uniquely by the location of the defect whether it is on inner race, outer race, or one of the rolling elements. Frequency analysis of vibration signals is therefore the most popular technique for detection of defects in rolling element bearings. The wavelet method which provides variable time and fast fourier Transform (FFT) to convert the time signal into its corresponding frequency components. A Fast Fourier transform reduces the complexity of computing the discrete Fourier transform.The discrete Fourier transform is obtained by decomposing a sequence of values into components of different frequencies. A cepstrum is power spectrum of logarithmic of power spectrum. The main reason for selecting the Acoustic Emission (AE) analysis in gear fault diagnosis is that it is a fundamentally different process used in Fourier transform analysis which is also called Time Synchronous Averaging technique. It was concluded that the averaging process gradually eliminates random noise because the random noise is not synchronous with the trigger signal. a filter combined by convolution into sums of their cepstra for linear separation. The independent variable of spectrum graph is logarithmic of power spectrum. The independent variable of spectrum graph is quefrency.

Vibration analyses of gear cracks and their effects on various parameters have drawn the attention of the researchers for a long time. Several models with varying degrees of freedom have been proposed by researchers to depict the vibration signal. The excitations caused by defects and errors have also been dealt in various ways in these studies. Gear failure can occur due to an excessive applied load, insufficient lubrication, manufacturing errors or installation problems. Gear failure is an unwanted event, as it involves a termination of the ability of the gear to perform the required function, and can entail serious and costly consequences. By implementing an appropriate maintenance strategy, identifying early faults in gears, the number of failures and unplanned stoppages can be reduced.

## 2 LITERAURE SURVEY

**Vikas Sharma, Anand Parey**[1] reviewed the literature of condition indicators for fault diagnosis of fixed-axis gearboxes, their characteristic frequency and statistical measurement for fault detection. Theyfound out that vibration signals are compound in nature and gearbox with multiple meshing pairs makes fault diagnosis more complex. They concluded that the input frequency of whole gear tranmission will be same as that of rotating frequency of gear and selecting the damage indicator is not related specifically to sensitivity. They have illustrated different condition indicators based on fault diagnosis techniques considering the effect of varying load and fluctuating speed.

**Ninoslav Zuber, Rusmir Bajric, Dragan Cvetkovic**[2] found out that fault feature extraction is a key point in condition monitoring and fault diagnosis. They explained that faults occuring in gearbox such as gears and bearing defects must be detected as early as possible to avoid fatal breakdowns of machines and prevent loss of production and human casualties. They concluded that the time domain signal in the gearbox usually changes when damages occur in a gear with both amplitude and content being different from those of the time domain signal of a normal gear.

**A.Parey and N. Tandon**[3] studied the effects of vibration on gears and various defects in gears causing vibrations. They have explained various terms used in Gear Dynamic Modeling like Flank deviation, dynamic factor, transmission error, backlash and external excitation. Different cases of impact has been discussed by them with the effect of mesh stiffness on the tooth surface with the help of graph of geairing stiffness as a function of time for one time period. Different mathematical models with their defects have been elaborated including the effects of friction in them with the equations of motion related to it. Friction increases the degree of freedom in any dynamic model perpendicular to the line of contact of the teeth in mesh. Sliding wear on gear flank reduces the dynamic contact load.

**AW Lees, PC Pandey**[4] analysed complete shaft bearing system as a set of segments, each segment terminated at a gear mesh. They applied the equations of constraints whcih can be imposed on that system and this leads to response which contains frequencies thast are of orders of shaft speed, as well as frequencies which are independent of shaft speed. The spectra form the gearboxes have been analysed and parameter have been calculated which is named as "Figures of Merit". These figures of merit have been found from long series of rig tests, to relate to certain types of fault. They found out that if a multiple of a exciting frequency corresponds to a critical speed of the system, there will be a component of response at this frequency. They concluded that no signs of instability have been observed on the mills possibly due to damping. They have shown that how tooth pitch errors give rise to components in the vibrational spectrum at frequencies other than the synchronous one. Hence, it is possible to calculate gear loadings and develop realistic criteria to judge the acceptibility of vibrational levels.

**James I. Taylor, Gardinier**[5] identified the importance of early identification of gear problems including those associated with the gear mesh. Specific defective gears are identified along with the number of defective teeth on each gear. They found out that the defective tooth on a gear can generate a hit or impact each time the tooth goes into mesh and the repetition rate of this impact is the speed of the gear. It was also seen that the broken tooth on the gear generates a pulse and hence the placement of transducer is critical. They concluded that in rotating machines, vibration frequencies generated by the rotation are equal to the number of events times the speed. They also found out that the presence of modulation may indicate a defective gear. They concluded that defects can be identified early enough to permit six months lead time before repair is required. This lead time facilitates planning and leads to catastrophic failure.

**RB Randall**[6] elucidated the advantages of cepstrum with respect to diagnostic power and repeatability. It is found that periodicity in cepstrum is due to echoes and from families of harmonics. Uniformly distributed wear only increase the components at the tooth-meshing frequency and its harmonics, and does not give rise to sidebands. It was seen that the independent variable in the cepstrum has dimensions of time known as quefrency. It was concluded that signal to noise ratio has a large influence on the results of practical cepstrum analysis.

It was observed that a general increase in spectrum levels at higher toothmeshing harmonics indicate greater distortion. It was seen that Cepstrum peak represents the average sideband spacing based on the whole spectrum range. It was concluded that determination of the basic modulating frequency is more important diagnostically than a division into amplitude and frequency modulation.

**Ninoslav Zuber, Rusmir Bajric, Rastislav Sostakov**[7] studied artificial neural networks and vibration analysis for the purpose of automated gearbox faults identification. They tested two types of gear failures, worn gears and missing teeth. They found out that out of the several methods of Artificial Intelligience which can be used for automatic fault identification of rotating machine artificial neural networks is the most applied one due to its ability to adopt novelties. They demonstrated the use of self organized feature map and artificial neural networks for automatic identification of missing and worn teeth in gearboxes that work under steady loads. It was concluded that self organized feature map can be used for preprocessing phase where a reduced set of vibration features should be defined as inputs in Artificial Neural Networks algorithm.

**M. Elforjani, D.Mba, A. Muhamaad**[8] monitored the seeded effects of worm gears with acoustic emission and comparison are made with vibration analysis. They developed an integrated approach to fault diagnosis using both wear debris analysis of worm gear oil and vibration analysis. A specifically designed test rig was employed for the investi gation which consists of an oil jet sprayed worm gearbox, driven by a reverse variable speed geared motor unit. They concluded that the study demonstrated the applicability of Acoustic emission technology in detecting defects on worm gears in working condition. They found out that the observations of continuous monitoring of gear tests revealed that acoustic emission parameters such as root mean square and energy are more reliable.

**Victor Skrickij, Marijonas Bogdevicious**[9] identified the most sensitive diagnostic parameters and determination of frequency intervals using the discrete wavelet transform in which the most significance increase in the values of diagnostic parameters can be seen. The resultsd in the frequency range were compared with the results of the classical method and it was found that the selected parameterin the proposed measuring range could better characterize the condition of gear unit. It was concluded that by using an extended frequency range, acoustic emission and signal monitoring of the gear unit is much more sensitive. The acoustic emission method is more sensitive to tooth fault identification in the hypoid gear than the vibro-acoustic signal measurement.

**D.P.Jena, Sudarshan Sahoo, SN Panigrahi**[10] validated proposed method using a customized gear drive test setup by introducing gears with defects in one or more teeth. A algorithm is used for measuring the angles between two or more teeth with a high level of accuracy. They concluded that active noise cancellation using acoustic signal from a healthy gear mesh as reference signal for adaptive Least Mean Square filter improve Signal to Noise Ratio of the acoustic signal from a faulty gear. The scalogram obtained from Adaptive Continuos Wavelet transform obtained is more informative and provides precise information on single and multiple defects.

**Ales Belsak, Joze Flasker**[11] found out that new wavelets are a generalization of biorhogonal wavelet systems. In the analysis, smoothness was controlled independently and discrete finite variation is used to optimize the synthesis blank. They concluded that quick changes can be done and the presence of damage at the level of individual tooth can be attained by using biorthogonal wavelet transform. They found out that impulses hidden in noise signals can be identified by means of wavelet transform.

**Yimin Shao, Daizhong Su, Amin Al-Habaibeh**[12] developed a new diagnosis algorithm based on the time impulses of an encoder to overcome the difficulty of fault diagnosis for helical gears at low rotational speeds. The acceleration signals and the encoder impulse signal are acquired at the same time. It was observed that the new algorithm was able to reduce noise and improves the signal to noise ratio by the Angular Domain Synchronous Average processing method. It was observed that the limitation of algorithm was there will be a time lag before it is performed on the live data, when the gears are running at low speed range. The other limitation of the algorithm is it is not fully capable to differentiate different types of localized tooth faults.

**Anand Parey, Ram Bilas Pachori**[13] used empirical mode decomposition (EMD) fro gear fault diagnosis in mechanical systems. The method decomposes the original signal into different frequency bands in time domain known as intrinsic mode functions. It was concluded that the kurtosis parameter is a better fault indicator if calculated for windowed second intrinsic mode function. The other parameters are found less sensitive to the spurious signal.

## 3. CONCLUSIONS

From the above literature survey we have compared the fault diagnosis of different types of gears and the various methods used for the identification of the fault diagnosis using different techniques like condition indicators, signal analysis and cepstrum analysis. It has been concluded that vibration signal analysis is a very effective tool in finding gear fault at early stage. It is being concluded from the above literature survey that comparative study of fault diagnosis using condition indicators and cepstrum analysis has not been done for the same specifications of a gear pair. Results need to be compared for the same set of outputs from different fault diagnosis techniques to find out the optimum method of fault detection.

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