Defect Detection Methods for Gears- A Review

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Abstract

The present review covers various types of defects in gears, how to detect and diagnose these defects, broad literature overview related to defects and condition monitoring (CM) techniques and finally, conclusions drawn from survey. Defect in a gear may cause high vibration and noise thereby decreasing the transmission efficiency. Many CM techniques are known for the defect detection and diagnosis of gears. Cepstrum analysis, vibration measurement, acoustic emission (AE) technique, noise monitoring and wear debris analysis are the prominent CM techniques used in industries. Vibration signals carry dynamic information of the machine and hence these signals are very useful for fault identification. AE signals identify defects earlier than vibration signals. Application of vibration and AE monitoring techniques to spur, helical and worm gears have been identified and summarized through wide literature survey. Most of the work have been reported in detecting and diagnosing defects in spur gears. Few literatures are also available for defect detection in helical and worm gears.

Keywords: Gears, Defects, Diagnosis and Condition-monitoring

1 Introduction

Gears may be defined as toothed wheels that transmit power and motion from one shaft to another shaft by means of successive engagement of teeth. Gears can be broadly categorized as: spur, helical, worm and bevel. Gears have wide utilities ranging from daily-life application to industries. Gear failure can lead towards costly and sometimes life-threatening consequences. In order to reduce gear failures, a systematic study of various defect detection techniques and their application to gears is necessary. This paper is an attempt to review various CM techniques applied for fault detection in different types of gears.

2 Gear Defects

Defect in a gear may cause high vibration and noise thereby decreasing the transmission efficiency. And thereby leading to catastrophic failure sometime. A broad classification of gear defects is given in Fig. 1[1].

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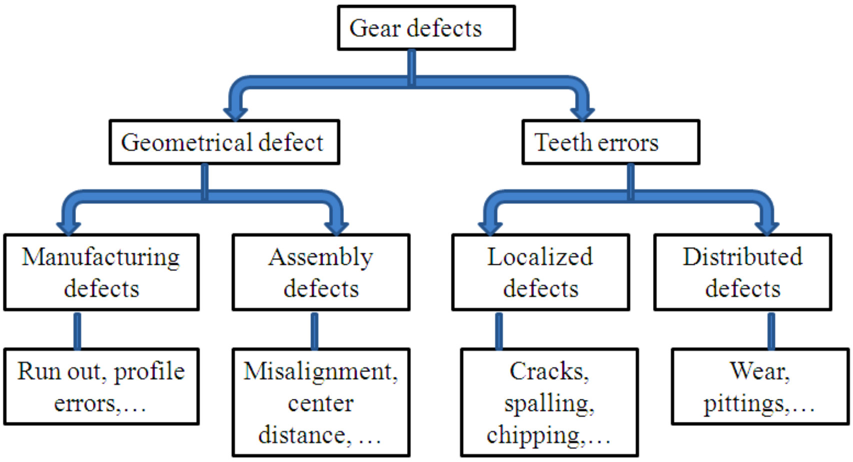

Figure 1 Gear defects classification [1]

3 Defect Monitoring

Many condition monitoring (CM) techniques are known for the defect detection and diagnosis of gears. Cepstrum analysis, vibration measurements, motor current signature analysis (MCSA), acoustic emission, noise monitoring and wear debris analysis are the prominent CM techniques used in industries and academic research.

In vibration measurement method, collected vibration signals are analysed in time domain, frequency domain and time-frequency domain. In time domain analysis, signal data are presented as amplitude vs time and analysed using statistical parameters such as RMS value, crest factor, and kurtosis. Crest factor and kurtosis are confidently used in the presence of significant impulsiveness. In frequency domain analysis, vibration signals are presented as amplitude vs frequency using Fourier transform. The main advantage of this method is that the change in gear mesh frequency and the occurrence of side-bands can be directly monitored to identify the presence or progression of defect. Recently time–frequency domain analysis has become popular. The wavelet method is used by the researchers in condition monitoring of gears due to its superiority in time and frequency resolution while processing the vibration signals.

Acoustic emission is defined as the spontaneous release of transient elastic waves in structures as a consequence of sudden localized changes in stress within the volume of the structure. These wave emissions are in the frequency range of 50 kHz to 1 MHz. Mechanisms like crack formation and propagation, fretting, plastic deformation etc. are responsible for AE wave generation. Varying stresses and strains act as sources of stress waves. Detectable elastic waves radiate away from the crack by dint of sufficient stress change, carrying a portion of the energy from the source. These AE waves can be detected by using piezo-electric transducers placed on the surface of the structure. If these waves are efficiently detected, they can provide an early warning of impending failure.

4 Defect Detection Techniques for Gears

AE and vibration signals were used to monitor worm gears with seeded defects by Elforjani et al.[2]. They found AE r.m.s to be more sensitive to the detection of defects than the vibration r.m.s. Elasha et al.[3] investigated the effectiveness of two vibration analysis techniques namely- Envelope analysis and Spectral Kurtosis (SK)for monitoring the faults in operational worm gearbox . They observed both the techniques to be able in identifying the presence of defects. An extension of this work is presented by Elasha et al. [4]. Along with already applied two vibration techniques (Envelope analysis and SK), authors experimented the feasibility of three statistical metrics- r.m.s, kurtosis and fm4* to perform worm gearbox diagnosis procedure. Authors found all the above mentioned techniques to be able to detect defect.

Badaoui et al. [5] presented an extended gear dynamic model and some advanced signal processing techniques. They developed a numerical procedure to simulate the dynamics of gears with local tooth damages such as pitting or spalling. Parey et al. [6] prepared an impact velocity model relating measurable vibration signal to the defect size on the flank of gear tooth. They verified analytical model with experiments. Using empirical mode decomposition (EMD) technique they decomposed experimental vibration signals.

Kar and Mohanty [7] tried to establish MCSA as the basis of condition monitoring of a multi-stage gearbox by using discrete wavelet transform (DWT). Attempt was to perform MCSA as a substitute to vibration signature analysis to detect fault and measure load fluctuation. Their findings suggested that MCSA along with DWT could be a good replacement for conventional vibration monitoring. The use of smoothed instantaneous power spectrum distribution in the detection of a local tooth defect in gears was introduced by Yesilyurt [8]. Theoretically, instantaneous power spectrum distribution and its smoothed version were presented. The instantaneous power spectrum transform was confirmed as better in display of weak signal components than the spectrogram.

A signal processing approach to load demodulation normalisation to monitor the condition of gears operating under fluctuating load conditions has been derived [9]. They examined the procedure on experimental data measured during constant, sinusoidal, step and chirp-load fluctuations for different damage severity levels. Authors also evaluated statistical parameters from the pseudo-Wigner–Ville distributions that had been calculated for the load-normalised acceleration signals averaged in the rotation domain.

The effects of tooth crack on the vibration response of a single stage gearbox with spur gears was investigated [10]. They utilized a lumped parameter model to simulate the vibration response of the pair of meshing gears. For understanding the change in the vibration response caused by the tooth crack, authors utilized several statistical indicators. They compared the performance of these indicators and analyzed their pros and cons.

Mohammed et. al. [11] presented a comparative study of the performance of the RMS and kurtosis values for three crack propagation scenarios while performing vibration-based fault detection. This paper presented an analytical approach for evaluating the time-varying gear mesh stiffness required for obtaining the dynamic response of three series of crack propagation scenarios. The crack model used in this work was a strong simplification of a real crack. A single stage twelve degree of freedom (DOF) spur gear model for describing the gyroscopic DOF was developed [12]. Authors utilized the analytically developed model for simulation of the studied gear system to examine, from a fault identification perspective. Authors used this presented model and three other models were utilized to simulate different crack sizes for the same gear system. Also, the authors evaluated gear mesh stiffness with a cracked tooth and presented the results of fault detection analysis applied on the dynamic response of the four models studied. Authors [13] analytically evaluated the time-varying mesh stiffness and did dynamic simulation after which they estimated the system's natural frequency by getting frequency response functions (FRFs). Because of mesh stiffness variation, the change in the FRFs was estimated in this study. Also, the FRFs were obtained with different crack sizes in the tooth root so as to perform fault detection analysis using the FRFs.

Mohammed and Rantatalo [14] introduced a new approach involving a short-time Fourier transform by taking the fast Fourier transform of successive blocks with different sizes corresponding to the time segments of the varying gear mesh stiffness according to the number of teeth in contact authors set the block size. With an objective of detecting cracks in an early stage and estimating their size, authors investigated the effect of the different crack sizes on the change in the dynamic response and the natural frequencies related to the gear mesh stiffness.

Li et al. [15] studied tooth root crack estimation using embedded modelling. An embedded model integrating a physical model of the gear box and a parametric representation in the form of truncated Fourier series of meshing stiffness was established in this work. Vecer et al. [16] described frequently used condition indicators in their paper. They tested the durability of helical gear manual transmission and thus examined the performance of some selected condition indicators to analyse the degree of gear wear using vibration signal acquired.

Tan et al. [17] did a comparative study on the diagnostic and prognostic capabilities of AE, vibration and spectrometric oil analysis of spur gears. They studied the phenomenon of natural pitting on spur gears. Authors examined vibration, AE and oil samples for correlation and comparison of these techniques to life degradation of the gears. Al Balushi and Samanta [18] presented a procedure for fault diagnosis of gears using energy-based features extracted from the time domain signals. They identified local AE activity successfully. They demonstrated the effectiveness of the features in diagnosing the gear conditions and in locating the faults using a laboratory test gearbox. Mba [19] reported on the application of AE for gear defect diagnosis. They examined possibility of gear defect detection from the bearing casing. They concluded AE to be a complimentary technique for gear health monitoring. Tan and Mba [20] analyzed the application of AE for defect detection of gear. They explored the source of AE generation from the gearbox in their work. They took a total of six experimental combinations: two speed and three load conditions. Tim et al. [21] determined an effective AE indicator for seeded gear defect detection. They employed an experimental test-rig that allowed for different sizes of defects to be seeded onto the test gears. They used three sets of torque for the experiment. They selected r.m.s as the AE parameter for the analysis of gear defect diagnosis. In this paper, authors presented the gear meshing AE transient response in the time domain. Authors concluded with reasons that seeded gear defect detection with AE was fraught with difficulties. Tan and Mba [22] presented an experimental investigation that assessed the effectiveness of AE for identification of seeded defects in helical gears.

Eftekharnejad and Mba [23] investigated the application of both vibration and AE techniques for monitoring the natural pitting on helical gears. They also mentioned some of the difficulties in applying AE to helical gears. Loutas et al. [24] studied the development of damage in artificially induced cracks in the gears using a single-stage gearbox. They conducted multi-hour tests and they acquired acoustic emission and vibration recordings. Pullin et al. [25] demonstrated automatic detection and location of common gear tooth defects. They designed a novel test rig to allow the fatigue loading of an individual gear tooth which was monitored using AE.

Authors [26] worked towards detection and localization of the gear failure occurrence for a gearbox operating under different load conditions. Initially, residual signal was evaluated using an autoregressive model with exogenous variables (ARX) fitted to the time-synchronously averaged vibration data and filtered time-synchronously averaged envelopes when the gearbox operated under different load conditions in the healthy state. The gear of interest was divided into several sections. Then, the fault detection and localization indicator was calculated from the residual signal. The proposed fault detection scheme was able to indicate the time of occurrence of the gear fault along with its location.

An efficient diagnostic technique[27] was proposed which consisted of fitting an autoregressive (AR) model to gear motion residual signals and then taking advantage of the noise-adaptive Kalman filter (NAKF) to decorrelate the signal to produce a white Gaussian sequence (or AR model residuals). A statistical measure was then applied to the AR model residuals to indicate the state of the gear of interest. Jena et. al. [28] tried to identify and localize the defect in gear and measured the angle between two damaged teeth in the time domain of the vibration signal. The vibration signals were captured from the experiments and the burst in the vibration signal was used in the analysis. The envelope technique was revisited for defect detection but was not found satisfactory in measuring the angle between two faulty teeth. A signal processing technique was proposed for filtering the noise and for measuring the angle between two damaged teeth.

5 Conclusion

Publications on acoustic emission and vibration analysis to gear fault diagnosis are widely available and the subject has been investigated for over a long period.

An attempt has been made to review gear defects, its monitoring and fault detection techniques and mainly two defect detection techniques (vibration and acoustic emission) for gears has been focused. Most of the work has been done in detecting and diagnosing defects in spur gears and the review indicates that both the techniques can be successfully applied for the defect detection of these gears. Few literatures are also addressed for defect detection in helical gears and worm gear boxes. But, there is a need for further studies on defect detection of these gears.

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