

Multi-fault diagnosis of gear system using vibration based signal processing technique



#¹V.S.Panwar, #²S.P.Mogal

¹vikas09panwar@gmail.com

²spmogal10@gmail.com

#¹² N.D.M.V.P.'s K.B.T. College of Engineering, Nashik, India

ABSTRACT

Presently there are some on-line vibration monitoring methods which do not require to shut down the machinery and can be used as in-flight diagnostic & trend monitoring device. However, so much work has to be accomplished on the detection and quantification of combined gear faults in a bearing-rotor-gear transmission system. The spectrum of multi gear fault becomes more complex, therefore, the signature of gear fault cannot be identified without applying special procedure to it. In this work, under variety of operating condition, vibration signature due to combined and individual damage to gear tooth were examined in both time & frequency domains for identification purpose. Joint time-frequency analysis such as wavelet transform was used in detecting & identifying various types of gear fault. The SVM (Support Vector Machine) based on MatLab was also used to classify the signals depending on different types of fault. The objective of this work is to develop an on-line health monitoring system to detect faults in gear transmission system. Considerable success has been achieved in this work to identify faults in gear system.

Keywords— Multi-fault, Monitoring, Wavelet Transform, SVM.

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I. INTRODUCTION

Competitiveness in the world has forced industries to reduce production losses and minimize breakdown cost. Vibration monitoring as part of the preventive maintenance program has been widely employed to enhance safety, efficiency, reliability, availability, and longevity in manufacturing processes and proved to be highly cost effective. Along with the development of signal processing, more and more signal processing tools, such as autospectrum, cross spectrum, cepstrum, and higher-order spectrum based on Fast Fourier transform (FFT), have been introduced to diagnose the faults in rotating machinery.

Nowadays rotating machine is widely operated in industries with extremely demanding performance criteria. So failure of any machine can be disastrous thus resulting in costly downtime. Condition monitoring and fault diagnosis is the most effective tool for ensuring the safe running of rotating machine. Fault diagnosis is conducted typically in the following phases: data acquisition, feature extraction, and fault detection and identification. As each rotating machine or component has its specific vibration signature

and any change in vibration signature can be consider to detect initiatory defect before it becomes severe. Signal analysis is mostly used method for fault diagnosis. In signal analysis, the important information contained in the signal is taken out and then principle features of the signals are extracted for fault diagnosis. Many signal analysis techniques have been implemented for fault diagnosis such as Waveform analysis, Time-Frequency analysis, Faster Fourier Transform (FFT), Spectral analysis, Order analysis, Time Synchronous Average, and probability density moments. Even though several techniques have been proposed in the literature for feature extraction, it is still challenge in implementing a diagnostic tool for real-world monitoring applications due to the complexity of machinery structures and operating conditions. This paper attempts to summarize and review the recent research and development of feature extraction methods in fault diagnosis of gear faults.

II. FAULT DETECTION METHOD

Fault detection and identification methods can be classified by the way process knowledge is incorporated in the signal processing, into model-based methods and signal-based methods. When a process is too complex to be modeled analytically and signal analysis doesn't yield an unambiguous diagnosis, a fault detection approach based on expert systems or artificial intelligence can be used.

A. Model-Based Methods

A model-based method uses the system inputs $u(k)$ and outputs $y(k)$. According to Isermann & Ball'e (1997), there are three basic categories:

System Identification And Parameter Estimation: using a system identification technique on input/output measurements, process parameters are estimated and compared with a nominal parameter set. The difference, or residual, is used as a fault indicator.

State And Output Observer: an observer, often a Kalman filter, uses knowledge of the nominal system model. A reference model is run in parallel to the observed process, which uses the controlled system input to estimate the system's state variables and reconstruct the system outputs. The residual, defined as the difference between the real and estimated output, can be used as a fault indicator. A special class of observer-based approaches is the multiple-model estimation approach.

Residual Generation: primary residuals are formed as the difference between the actual plant outputs and those predicted by the model; these residuals are then subjected to a linear transformation to obtain the desired fault-detection and isolation properties, such as sensitivity to faults, reduced (or no) sensitivity to noise, etc. Model-based techniques require a sufficiently accurate mathematical model of the supervised process.

B. Signal-Based Methods

A signal-based (or feature-based) method for fault detection is based on analysis of the measured output signals $y(k)$. Suitable features of the measured signals are used to evaluate the operating conditions. These features can be in both time and frequency domain, some examples are the signal mean, variance, skewness, kurtosis, crest factor or the power in a certain frequency band. Signal-based fault detection methods are particularly interesting for vibration detection. Vibration spectra can be compared to find deviations in rotational frequencies, which may correspond to particular instabilities. However, this thesis only considers model-based fault detection schemes.

C. Expert System And Artificial Intelligence Approaches

Sometimes a process is too complex to be modeled analytically and a regular signal analysis approach doesn't yield a reliable FDI scheme, e.g. certain fault combinations have different effects on the system behavior. It is then possible to classify faulty behavior by using qualitative process knowledge to evaluate relations between measured signals and the current operating conditions. These methods are further divided into probabilistic methods, fuzzy logic techniques and artificial neural network approaches

Diagnostics is understood as identification of a machine's condition/faults on the basis of symptoms. Diagnosis requires a skill in identifying machine's condition from symptoms. The term diagnosis is understood here similarly as in medicine. It is generally thought that vibration is a symptom of a gear box condition. Vibration generated by gearboxes is complicated in its structure but gives a lot of information. We may say that vibration is a signal of a gearbox condition. To understand information carried by vibration one have to be conscious aware of a relation between factors having influence to vibration and a vibration signal. In order to detect (and diagnosis) an impending failure, a good understanding of the evidence relating to the failure mode and methods of collecting and quantifying the evidence is needed. Although many faults may be easily detectable by physical examination of a component, using techniques such as microscopy, X-ray, dye penetrates, magnetic rubber, etc., these methods usually cannot be performed without removal of, and in some cases physical damage to the component. Whilst physical examination techniques still play a critical role during manufacture, assembly and overhaul, they are impractical in an operational large transmission system and other (non-intrusive) fault detection methods need to be employed for routine monitoring purposes. Most modern techniques for gear diagnostics are based on the analysis of vibration signals picked up from the gearbox casing. The common target is to detect the presence and the type of fault at an early stage of development and to monitor its evolution, in order to estimate the machine's residual life and choose an adequate plan of maintenance. It is well known that the most important components in gear vibration spectra are the gear meshing frequency (GMF) and its harmonics, together with side bands due to modulation phenomena. The increment in the number and amplitude of such side bands may indicate a fault condition. Moreover, the spacing of the side bands is related to their source. Source identification and fault detection from vibration signals associated with items which involve rotational motion such as gears, rotors and shafts, rolling element bearings, journal bearings, flexible couplings, and electrical machines depend upon several factors as follows:

- (i) The rotational speed of the items.
- (ii) The background noise and/or vibration level.
- (iii) The location of the monitoring transducer.
- (iv) The load sharing characteristics of the items, and
- (v) The dynamic interaction between the items and other items in contact with it.

The main causes of mechanical vibration are unbalance, misalignment, looseness and distortion, defective bearings, gearing and coupling in accuracies, critical speeds, various form of resonance, bad drive belts, reciprocating forces, aerodynamic or hydrodynamic forces, oil whirl, friction whirl, rotor/stator misalignments, bent rotor shafts, defective rotor bars, and so on. Some of the most common faults that can be detected using vibration analysis in gears are tooth meshing faults, misalignment, eccentric gear, cracked and/or worn teeth.

F.K.Choy et al. in [1] explained the modal synthesis approach of the analysis treats the uncoupled lateral/torsional modal characteristics of each stage or component independently and its knowledge of modal excitations provide an understanding of the vibrational characteristics of the system. Wavelet transform can be considered as a mathematical tool that converts a signal in time domain into a different form, i.e. a series of wavelet coefficients, in time-scale domain. A wavelet function, which is a small wave, possesses oscillating wavelike characteristics and concentrates its energy short in time, is needed to implement the wavelet transform. Traditionally, the wavelet transform can be categorized as CWT, DWT, and WPT as explained in [2].

Recognition of faults in tothing during non-stationary start-up and run-down of gear drives has been explained by G. Meltzer and Yu Ye Ivanov in [3]. They achieved this by means of the time-frequency analysis. As a practical case study, they investigated a planetary gear for passenger cars. New exponential smoothing kernels with respect to the known-in-advance angular acceleration of gear drive were created. These kernels must be adapted in the case of an in-advance-unknown course of rotational speed. They created and applied successfully new smoothing kernels for the Choi-Williams distribution according to the linear and known-in-advance course of rotational speed. By this, they get a new access to the fault diagnosis of machines with unsteady rotational speed. Some researchers have used different methods of fault diagnosis for detecting some particular defect like crack or spalling.

A. Belsak and J. Flaker in [4] have considered the most undesirable damage that can occur in gear units is crack in the tooth root. For diagnosis purpose they collected the time signals experimentally and afterwards amplitudes of time signal are, by time-frequency analysis, presented as a function of frequencies in spectrum. Vijay karma & Himanshu borade in [5] had also performed the diagnosis for particularly studying the effect of spalling. Fault diagnosis of a spur gearbox having spalling defect in driver gear using narrow band demodulation technique through MATLAB software had been performed. Omar D. Mohammed et al. in [6] had assumed different analytical scenarios for crack propagation in the gear tooth root. They presented an investigation of the performance of statistical fault detection indicators (the RMS and kurtosis) for three different series of crack propagation scenarios, to compare these scenarios from a fault diagnostics point of view.

Amir Hosein Zamanian & Abdolreza Ohadi in [7] presented a new method for feature extraction that is based on maximization of local Gaussian correlation function of wavelet coefficients and signal. The effect of empirical mode decomposition (EMD) to decompose multi-component signals to intrinsic mode functions (IMFs), before using of local Gaussian correlation was discussed.

T.Y.Wu et al. in [8] explained about the feasibility of utilizing the instantaneous dimensionless frequency (DLF) normalization and Hilbert-Huang Transform (HHT) to characterize the different gear faults in variable rotating speed. The analysis results demonstrate the capability and effectiveness of the proposed approach for characterizing the gear malfunctions at the DLFs corresponding to the meshing frequency as well as the shaft rotating frequency. The support vector machine (SVM) is then employed to

classify the vibration patterns of gear transmission system at different malfunctions.

Xiaochun Wu et al. in [9] discussed recent progress of classical and advanced filters for the condition monitoring and fault diagnosis. Filtering techniques have been successfully used in the field of condition monitoring and fault diagnosis. By the use of signal filtering, the impending system fault can be revealed effectively to prevent the system from malfunction.

D.P. Jena et al. in [10] identified and localize the defect in gear and measure the angle between two damaged teeth in the time domain of the vibration signal. A signal processing scheme is proposed to filter the noise and to measure the angle between two damaged teeth. The proposed technique consists of undecimated wavelet transform (UWT), which is used to denoise the signal. The analytic wavelet transform (AWT) has been implemented on approximation signal followed by a time marginal integration (TMI) of the AWT scalogram.

N. Saravanan & K.I. Ramachandran in [11] given the application of fast single-shot multiclass proximal support vector machine for fault diagnosis of a gear box consisting of twenty four classes. The statistical feature vectors from Morlet wavelet coefficients are classified using J48 algorithm and the predominant features were fed as input for training and testing multiclass proximal support vector machine

V. EXPERIMENTATION

Experimental setup consists of following components :

- Electric motor
- Gear Pair
- Rigid Coupling
- Shaft
- Bearings
- Pulley
- Belt
- Spring Balance
- Frame

An experimental setup is shown in fig.1. It consists of an single phase electric motor (of 0.5 hp & 1440rpm) for driving the system, a flexible coupling for connecting the motor shaft and input shaft, two shafts (one input shaft of diameter 25mm and one output shaft of diameter 30mm) of length 600mm each, one gear pair (pinion & gear), four pedestal bearing (two on input shaft & two on output shaft) and one pulley of diameter 200mm & thickness 45mm for applying the load. The load will be applied with the help of nut & bolt by tighten the belt on the circumference of pulley and the load applied will be measured with two tube type spring balance as shown. All components are mounted on a C-channel frame. The gear pair used here is spur gear pair. The pinion has 18 teeth and gear has 38 teeth while the diametral pitch of gear pair is 10mm. Material used for gear pair is mild steel whereas material for the shafts is stainless steel.



Fig.1. Experimental Set-up

VI. EXPERIMENTAL PROCEDURE

For multi-fault diagnosis of gearing system, in this experiment, we will investigate the co-relation between vibration analysis and gear system fault. This will be achieved by vibration analysis of a gear system. Therefore, an experimental model is prepared so that a series of tests can be conducted by using FFT signal processing technique for the operating hours of gear system. Vibration data will be regularly collected. Overall signal processing data produced by vibration analysis will be compared with vibration spectra of healthy gearbox, in order to quantify the effectiveness of the vibration based signal processing technique.

In this work, under variety of operating condition, vibration signature due to combined and individual damage to gear tooth were examined in both time & frequency domains for identification purpose. Joint time-frequency analysis such as wavelet transform was used in detecting & identifying various types of gear fault. Afterwards, in order to classify the different faults, the SVM (Support Vector Machine) classifier based on MatLab will also be used to classify the signals depending on different types of fault.

VII. CONCLUSION

Fault diagnosis techniques are improving all the time given advances in disciplines such as statistics, signal processing, and computing science. Time domain techniques include raw signals, filter based signals, stochastic and model based methods. The statistical moments such as mean, covariance, and kurtosis can be calculated and compared with a threshold to detect rotating machinery faults. Frequency domain features are generally more consistent in the detection of damage than time domain parameters. In addition, time frequency techniques are also being researched to analyse certain component information required for specific applications. The proposed method presents signals with fine resolution and sparsity. This leads to relatively straightforward interpretation of a signal, which is often contaminated by noise. Furthermore, researchers are increasingly interested in automating the diagnosis procedure using feature extraction techniques. Tools and techniques in artificial intelligent systems such as expert systems, SVM, PSVM, neural networks, and fuzzy inference systems are being used in conjunction with some of the more powerful techniques described above.

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