ISSN 2395-1621

Wavelet Transform Based Insights in Gear Fault Diagnostics

#1 A.S. Bhandwalkar, #2 P. B.Bawa

[1]bsarchana79@yahoo.co.in
[2]prashantbawa@hotmail.com

#12 L.G.N.S.C.O.E, Nashik, India

ABSTRACT

Machine condition monitoring (CM) is a fairly settled technique of proactive maintenance. Vibration signature analysis for fault detection is most proven and accepted technique. Wavelet transform technique has emerged as most signals contain instantaneous impulse trains and other elements which are transient and non-stationary in nature however not detectable by FFT technique. The WT decomposes a signal into different frequencies with different resolutions. It magnifies short lived high frequency phenomena and reduces long lived low frequency phenomena. This property of wavelet transform can be applied for fault detection of single stage gear box.Vibration signals acquired from experimental setup are analyzed by wavelet transform toolbox. The paper discusses investigations based on these studies and looks for the possibility of building full gearbox model to simulate real time situation. Proposed Matlab Simulink model of gearbox is expected to support experimental studies.

Keywords- **condition monitoring, gear fault diagnosis, wavelet transform**

ARTICLE INFO

Article History

Received :18th November 2015

Received in revised form :

19th November 2015

Accepted : 21st November , 2015

Published online :

22nd November 2015

I. INTRODUCTION

Machine condition monitoring is a powerful tool for early detection of fault and hence predicts upcoming failure. The aim of condition-based maintenance is to eliminate machinery breakdown by assessing the condition of the machine, identifying failure and enabling corrective action prior to failure.Geared transmission systems are widely used to transmit power, torque. Performance of transmission system depends greatly on the integrity of the gear. Hence, health monitoring and fault detection in geared systems have attracted many researchers. Often, as a result of inappropriate operating conditions, gear faults frequently occur in practice. Much effortshas gone into developing reliable methods for fault detection in gearboxes. Some proven techniques include oil analysis, temperature distribution analysis, most popular today, vibration analysis.

Vibration measurement, which is the most widely used condition monitoring technique in industry, because of its proven ability to detect the early presence of faults, can identify only 60% to 70% of machine faults. Many conventional techniques are power spectrum, cepstrum, time-series analysis, are well established and have proved to be very effective in machinery diagnostics. But these techniques are not suitable for non-stationary signal analysis. To deal with non-stationary signal new techniqueshave been proposed such as time–frequency distribution [3], wavelet [2] and higher-order statistics [3].Among these new techniques, wavelet analysis possesses particular advantages for characterizing signals at different localization levels in time as well as frequencydomains. It has a wide variety of applications in many engineering fields such as signal processing, image processing, pattern recognition, seismology, etc. For mechanical fault diagnosis, wavelet analysis has been used in gear diagnosis [2], rolling bearing diagnosis [3], compressor diagnosis [3] and diesel engine diagnosis .Wang and McFadden [10], for example, used orthogonal wavelets such as the Daubechies[3] and harmonic wavelets to disclose abnormal transients generated by early gear damage from gearbox casing vibration signal.

The purpose of this paper is to extend Wavelet transform technique for gear fault diagnostics. For this purpose we have seeded following faults ie 1) broken tooth & 2) Cracked tooth in gears. Time response are acquired from gearbox with the help of fast Fourier transform (FFT) and then analyzed by wavelet transform. Signals are compared in Time, Frequency & time frequency (wavelet)domain for fault diagnosis. MATLAB Simulink model of single stage gear box is developed for healthy & faulty condition. Results of both Simulation and Experimentation are compared

A. *Fourier Transform*

For vibration analysis Fourier transform is used to convert time domain signal into frequency domain signals by integrating given function over entire time period. The Fourier Transform is a tool that breaks a waveform (a function or signal) into an alternate representation, characterized by sine and cosines. The Fourier Transform shows that any waveform can be re-written as the sum ofsinusoidal functions. Fourier transform of non-periodic function x(t) is given by[7]

$$X(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} X(\omega)e^{i\omega t}d\omega \qquad (1)$$

$$X(\omega) = \int_{-\infty}^{\infty} X(t)e^{-i\omega t}dt \qquad (2)$$

Where ω is fundamental frequency. Using Fourier transform signal can be converted from time domain to frequency domain signal. It is suitable to analyze stationary signals which get repeated over a period of time. Fourier basis elements are not localized in space and hence are not suited for analyzing non-stationary, transient signals To overcomethis limitation Short time Fourier transform (STFT) technique has been developed for capturing non stationary signals. But it has also limitation of constant window size

B. Wavelet Transform

Wavelet Transform (WT) technique is used decompose the vibration signal into time series into time-frequency space, it is possible to determine not only the existing frequencies in the signal but also the duration of each individual frequency in time [3]. This is highly advantageous in examining vibration signals from faulty rotating machinery, where either large or small scale changes in the vibration may occur whether the fault is distributed or local [2]. When monitoring gearbox condition, WTs are used primarily to identify all possible transients in vibration signals which are generated by faults. WTs possess multiple resolutions for localization of short time components, enabling all possible types of gear fault to be displayed by a single time-scale distribution resulting from the transform [8].

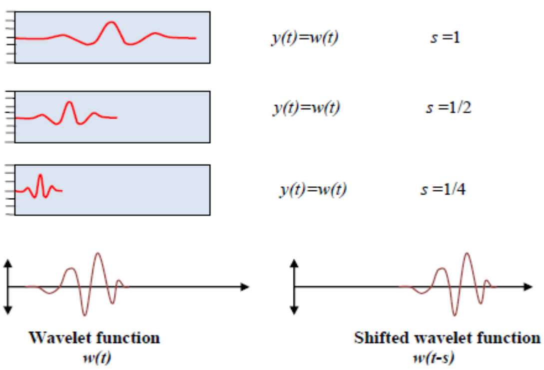

Fig. 1 Wavelet Transform scaling & shifting

The basis of the STFT approach is multiplication of the sine and cosine signals by a fixed sliding resolution. In the case of the WT method, the window is already oscillating and is called a mother window. The mother wavelet, rather than being multiplied by sine and cosine, is expanded and contracted depending on the value of the dilation parameter. Other wavelets are then generated by the mother wavelet, and it is this which forms the basis of wavelet analysis. The Wavelet Transform can be seen as decomposition of a signal into a set of basis functions called wavelets, obtained from a signal prototype wavelet by dilations, scaling and shifts.

The Continuous Wavelet Transform (CWT) of a function *y(t)* is defined in the time and frequency-domain as:

$$CWT(s,u) = \int_{-\infty}^{\infty} y(t)\frac{1}{\sqrt{s}}w^{*}\left(\frac{(t-u)}{s}\right) dt , \qquad (3)$$

Where: $w((t-u))/s)$ is the mother wavelet at scale *s* (scale or dilation factor) which determines frequency content, and location *u* (shift or translation parameter) which gives the time location of the wavelet.$w^{*}$is the complex conjugate of the analyzing wavelet *w(t).* A small *s* produces a high frequency (contracted) wavelet when high time resolution is required, while a large *s* produces a lowfrequency (dilated) wavelet when high frequency resolution is required.

II EXPERIMENTAL SETUP

In order to evaluate gearbox condition monitoring (CM) techniques, experimental work was carried out on a gearbox test rig developed at the SRES, Kopargaon. The gearbox test rig consists of a 3-phase motor, a single stage spur gearbox, shaft couplings and a load device, as shown in Figure 2. The input power to the gearbox is through AC motor which is coupled to gear shaft through coupling. Output shaft of gearbox is connected to rope brake dynamometer to transmit power from motor to dynamometer through gearbox. The schematic figure of vibration measurement for fault diagnosis of gearbox shown in Fig. 2. Gear box and gear details are as mentioned in tables 1 and 2

Table 1 Gear box details

Sr No	**Parameters**	**Specification**
1	Power	0.5 Hp
2	Input rpm	1440 rpm
3	Input frequency	1440/60 =24 Hz
4	Output rpm	565 rpm
5	Output frequency	818/60 =13.63 Hz

Fig. 2 Experimental setup

Table 2 Gear specifications

Sr No	Description	Pinion	Gear
1	No of teeth	26	46
2	Input rpm	1000	560
3	Rotational frequency	24	13.63
4	Tooth meshing frequency	624	624
5	Module	2.11	2.11
6	PCD	54.86	97.06
7	Reduction ratio	=46/26 = 1.76	
8	Contact ratio	1..67	

III TEST PROCEDURES

The vibration signals were collected using accelerometer mounted on the gearbox bearing refer fig 1. Vibration signals are collected at 500rpm, 1000rpm& 1440 rpm at constant load. The collected signal consist of three data sets: one for a healthy gear and two for faulty gears, which were all collected under the same operating conditions.

Fig. 3 Broken tooth

IV. TIME DOMAIN ANALYSIS

Conventional time-domain analysis uses the amplitude and temporal information contained in the gear vibration time signal to detect gear faults. The amplitude of the signal can be used to indicate that a fault is present and the periodicity of the vibration can then indicate a likely source for the fault. Time domain approaches are appropriate when periodic vibration is observed and faults produce wideband frequencies due to periodic impulses. Use of the waveform enables changes in the vibration signature caused by faults to be detected, but it is difficult to diagnose the source of faults.It is well known that each rotating machine will produce its own spectrum of frequencies. If the baseline vibration of a healthy machine is compared to the signal of a similar machine running at the same speed and under similar conditions, any increase over the baseline at any forcing frequency can indicate the presence of abnormalities in the machine. The baseline vibration signals (waveform) were recorded bythe transducer for250 seconds. Figure 4,5 shows the gearbox vibration waveform for healthy and faulty gear systems

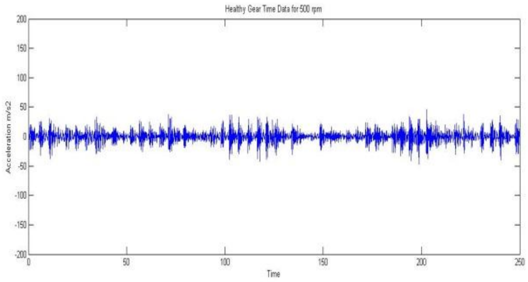

Fig 4 Time domain signature for healthy gear

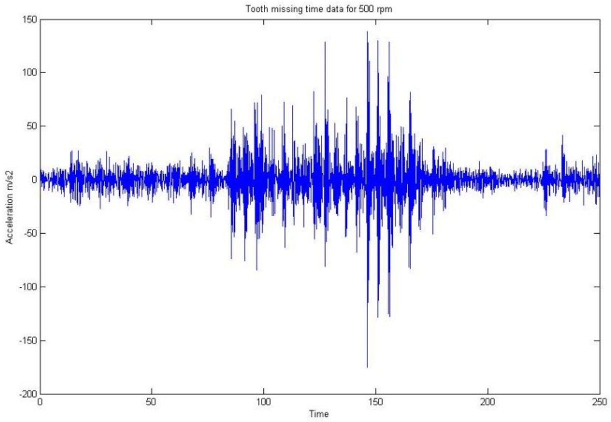

Fig 5Time domain signature for faulty(broken tooth) gear

V. FREQUENCY (SPECTRAL) DOMAIN ANALYSIS

For machines operating with known constant speed, the vibration frequencies of the vibrations produced by each component in the machine can be estimated therefore, any change in vibration level within a particular frequency band can be related to a particular component. Analysis of relative vibration levels at different frequency bands can provide some diagnostic information.The fundamental excitation frequencies of the gearbox can be calculated from Equations 4. Examination of theamplitude of the frequency spectrum of the vibration signal will often point to a specific gear in the gearbox as the source of a fault. In fact, a change in amplitude at any of these excitation frequencies should be taken as an indication of a fault in the gears. The most importantgearbox vibration is a result of tooth mesh rate, which can be calculated using Equation 4.

$$f_m = N f_r. \tag{4}$$

where; f_m = mesh frequency, N = no of teeth and f_r. = rotation shaft frequency Any significant increase in the amplitude of the peak in the spectrum corresponding to f_m with no corresponding change in speed or load strongly suggests a fault is developing

As seen in Figure 6,7 local defects such as gear tooth breakage are often found in the vibration spectrum through changes in amplitude of particular frequencies (sidebands around the gear meshing frequencies fm11) Sidebands generated by either amplitude modulation or frequency modulation of the vibration signal often provide useful information. Amplitude modulation is attributed to tooth fracture or eccentricity of the gear or shaft with a damaged tooth generating pulses at a rate equal to the gear speed . Randall has claimed that the first three gear meshing harmonics and their sidebands provide sufficient information for the successful identification of gear faults.

Therefore, changes in the amplitude of a particular frequency peak or sidebands of a signal can provide a good indicator of potential gear failure.

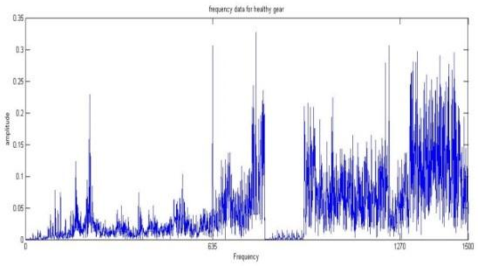

Fig. 6 Frequency domain signature for healthy

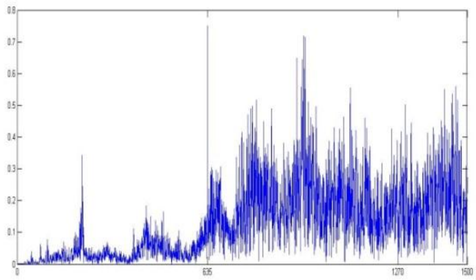

Fig. 7 Frequency domain signature for faulty(broken tooth) gear

The results presented in Figures 6 and 7 show that the spectral amplitude values corresponding to the fundamental meshing frequencies vary with theseverity of the gear faults and the operating condition. There is no consistent increase in their amplitudes with the introduction of faults and with an increase in operating conditions. As a consequence, these features cannot be used to indicate faults effectively.

II. VI. SIGNATURE IN TIME FREQUENCY DOMAIN – WAVELET TRANSFORM

As indicated in the time domain signals, vibrations from the gearbox clearly have many local spikes. As well as this, it can be seen that gears with local faults produce short transients. These features of signals can`t be characterized by normal frequency analysis, instead a joint time-frequency method is often used for analyzing them Figures 8 and 9 shows the continuous wavelet transform (CWT) results in colour images for healthy & faultyoperating conditions respectively.For the healthy gear under low operating conditions, the results show that the amplitude of the CWT is relatively smooth along the time direction, indicating that the gear transmission is relatively stable. However, a set of high amplitude signals are observed within the high frequency range data.

In the case of broken tooth fault, many sets of high amplitude patches occur. Although no clear repeat patterns are observed over the meshing period, they cannot all be treated as noise Nevertheless, the overall amplitude looks higher compared with that of the healthy gear, which may indicate the presence of the fault.

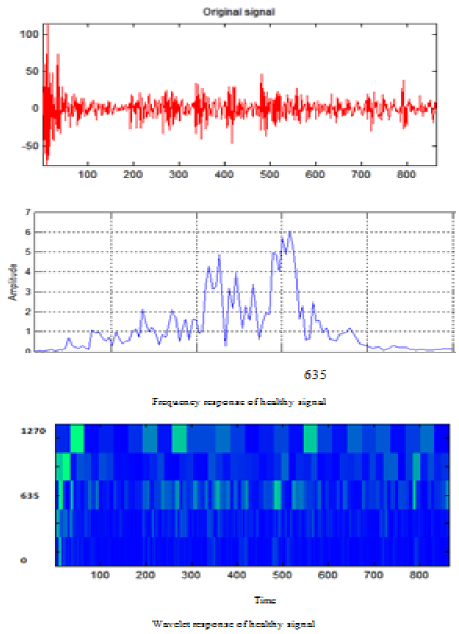

Fig. 8Healthy gear in time frequency & wavelet domain

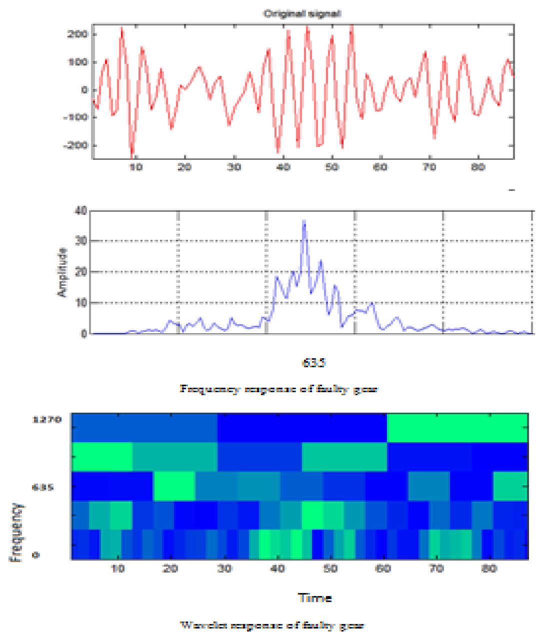

Fig.9Faulty gear in time frequency & wavelet domain

VII. GEAR FAULT SIMULATION

Dynamic modeling of gear vibration allows a deep understanding of the mechanisms which generate vibration in gear transmission systems. Moreover, dynamic modeling helps to characterize the changes of the dynamic properties due to various types of gear faults.Single stage gearbox model is developed in MATLAB Simulink. Two different types of severities of a local type fault were simulated. Fault simulation was carried out individually (one fault at a time) and the faults were artificially introduced in the gearbox shown in Fig 10. In an ideal situation, the faults should be introduced onto the same healthy gear, with one tooth missing & cracked tooth. Simulation work is under process.

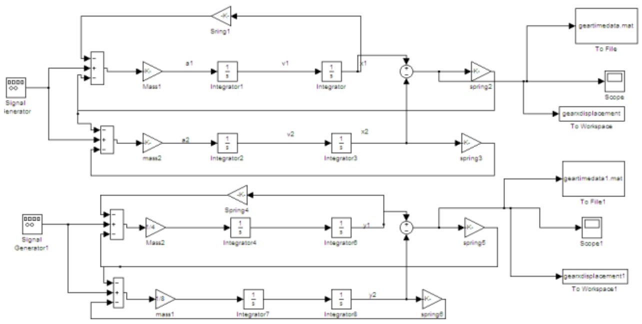

Fig.10 Simulink model of single stage gearbox

III.VIII. CONCLUSIONS

Vibration signal analysis techniques using FT, CWT techniques are used for fault diagnosis of single stage gearbox. Vibration studies are carried out for healthy as well as faulty condition. Matlab Simulink model is developed for single stage gearbox. Vibration acceleration signals have been studied for healthy & faulty gear in both time & frequency domain. Also results has been compared. CWT is used for damage detection of gearbox & found effective tool for damage detection. Experimental results agree that CWT is effective for fault diagnosis. This work can be extended towards simulation of real time fault detection.

ACKNOWLEDGMENT

Thanks to Prof. P. B.Bawa for his valuable guidance & continuous support during this work.

REFERENCES

[1] G. Dalpiaz, A. Rivola and R. Rubini, Effectiveness and sensitivity of vibration processing techniques for local fault detection in gears, Mechanical Systems and Signal Processing 2000

[2] N. Baydar and A. Ball, Detection of gear failures via vibration and Acoustic signals using wavelet transform, Mechanical Systems and Signal Processing 2003, 17(4), 787–804

[3] Z. K. Peng, F.L. Chu Application of the wavelet transform in machine condition monitoring and fault dignostics: a review with bibliography, Mechanical systems & signal processing 2004 199-221

[4] Ales Belsak, JozeFlasker Wavelet analysis for gear crack identification, Engineering Failure Analysis 2010 664–671 2009

[5] J. Rafiee , M.A. Rafiee, P.W. Tse Application of mother wavelet functions for automatic gear and bearing fault diagnosis, Expert Systems with Applications 2010, 4568–4579

[6] HocineBendjama, Salah Bouhouche, and Mohamed SeghirBoucherit Application of Wavelet Transform for Fault Diagnosis in Rotating Machinery, International Journal of Machine Learning and Computing, Vol. 2, No. 1, February 2012

[7] Al-arbi, Salem ,PHD Thesis condition monitoring of gear Systems using vibration analysis

[8] Fakhfakh, T., Chaari, F., and Haddar, M.- Numerical and experimentalanalysis of a gear system with teeth defects. Int. J Adv Manuf. Technol., 25:542-550. 2005

[9] Dudley, D.W. - Gear Handbook. NY, McGraw-Hill Book Co. Inc., ISBN:0070179034, 1962.

[10] Wang W.J., McFadden P., Application of wavelets to gearbox vibration signalsfor fault detection, Journal of Sound and Vibration 192 (5) 927–939, 1996

