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Condition Monitoring of Gear Box using Acoustic Signals

Talluri Nikhil, Tejas C, Thanya Dechamma MS, Syed Abdul Rahman and Madhusudana CK*

Department of Mechanical Engineering, PES College of Engineering, Mandya 571401, India. E-mail:

Abstract

Condition monitoring is a process to monitor the respective parameters of specified machinery to identify any occurrence of significant changes over a period of time. Condition monitoring is a predictive approach that predicts the condition of specified machinery by using sensor data that measures different parameters. Gear system is one of the power transmission systems that is used to transfer motion and torque between machine components. Gear is imposed to various kinds of loads and with different kinds of speeds that lead to wear out of tooth profile and/or other anomalies. Condition monitoring of gears plays a very important role in the detection of gear abnormalities which helps prevent catastrophic failure before the fault progresses. In this research work, condition of the gear is analysed using signal processing techniques, based on Sound signal. The signals are collected by microphone along with the data acquisition system during the operation. Signal processing techniques such as Fast Fourier Transform (FFT) and Continuous Wavelet Transform (CWT) are used to monitor the condition of gears. Amongst all frequencies of the gear, 800 Hz is the dominant frequency which recognizes the different conditions in spectrum plot whereas in CWT plots, the variations in 3D plots for different conditions of gears can be seen. Hence these techniques can be recommended for condition monitoring of gears.

Keywords: *Gear box, Condition Monitoring, Sound Signal, Signal Processing Techniques.*

1.0 Introduction

Condition monitoring is an important method for early detection of faults or unconditional behaviour of the machine components in the respective machinery. Condition monitoring helps in avoiding unplanned downtime; it helps to eliminate unnecessary maintenance, improving the safety measures of the machinery, and many other advantages. Condition monitoring systems play a vital role for researchers in the development of machine components[5]. Gears are a very important component used in the majority of the industries. The gear system is very compact. They have a long life, can attain a high-velocity ratio with minimum space, and they help to transmit power.

As gears withstand variable loads during the motion and transmission of power, it undergoes wear and tear of the surface, which results in the unconditional behaviour and defects in the gear. So, it is very important to carry out research on condition monitoring of gears. The condition monitoring system enables early detection of gear cracks and helps in stopping the gear crack progress[4].

There are different condition monitoring techniques which have been developed over the years to monitor the condition of the gearbox, like vibration analysis, acoustic emission analysis, sound signals analysis, wear debris analysis, thermography, oil analysis. Earlier the research on the gear failure detection was done using time averaged vibration signal, amplitude, cepstrum and phase modulation techniques to find the abnormalities and indicate the faults without providing information about the location and the severity of the faults[2].

*Author for correspondence

Meshing of gears creates friction causing abrasive wear which results in surface imperfection and faults. For gear tooth flanks, a change in surface roughness is often the clearest sign of surface damage. In gearbox wear induced gear tooth surface erosion is an inevitable phenomenon, and it can lead to destructive damage to the gear teeth and a significant reduction in the remaining useful life of the gearbox[3]. The detection of the specific gear faults in multistage gearboxes is often difficult. The analysis of sound signals is one of the important techniques to identify the defects in running gears. This paper presents a research work carried out on condition of the gears at particular intervals of time period (100 hours).

Signal processing is a major engineering sub-field that focuses on analysing, modifying and synthesizing signals. These techniques are used to improve transmission, storage efficiency, subjective quality, to find defects in the components and necessary to post-process measured signals. It indicates the state of the structure. Common signal processing techniques are Fast Fourier Transform (FFT), Discrete Fourier Transform (DFT), Short time Fourier Transform (STFT), Continuous Wavelet Transform (CWT), etc. In this paper we have focused on the effectiveness of FFT and CWT techniques. In Sound signal analysis. FFT is one of the most widely used in signal processing techniques[1]. It is a mathematical transformation of a signal from the time domain to frequency domain representation. FFT analysis can provide high resolution in the frequency domain and analyse sound signals of a certain frequency in detail.

2.0 Experimental Set up

In this present research work, a back-to back power re-circulating type of oil lubricating FZG spur gear test rig is used to carry out the sound signal analysis of the gearbox as shown in Figure 1. It consists of slave gears and test gears mounted on the ends of two parallel shafts. One shaft has a

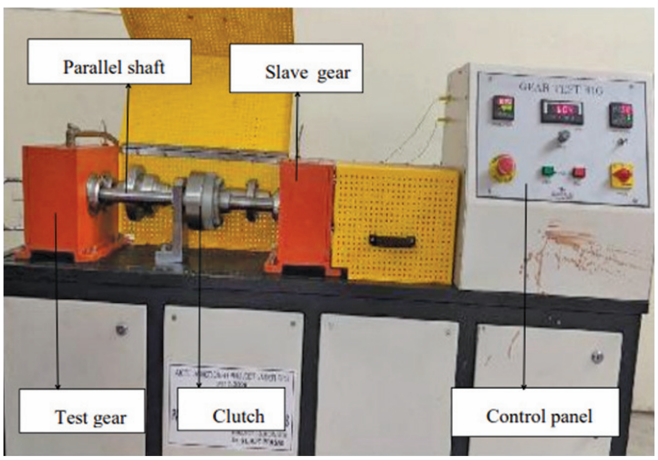

Figure 1: FZG gear test rig

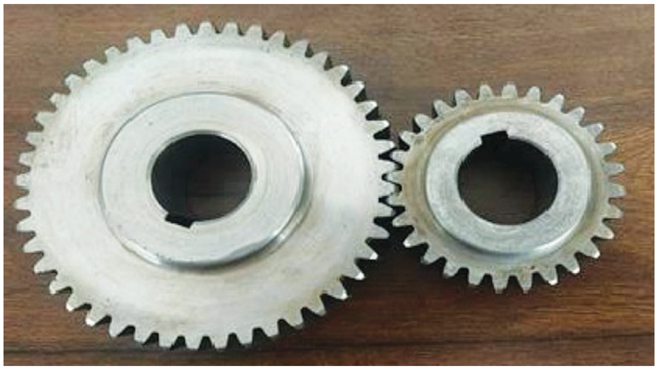

Figure 2: Spur Gears

load clutch through which the load is applied to the test gears using a lever arm and weights.

The gears mounted on parallel shafts in the test gearbox are spur gears. EN24-steel-alloy spur gears shown in Figure 2 are used to perform the experiment and specifications are briefly listed in Table 1.

In this study, sound signals were acquired using a microphone (PCB 377B02, sensitivity: 50 mv/Pa, frequency range: 5 to 8000 Hz) which is placed near the pinion gear and 4 analog input channels, 24 bit, the delta-sigma-DAQ system was used for signal conditioning and processing of sound signals.

The experiment was conducted at a speed of 600 rpm and sound signals were acquired at regular intervals of time with no load, 50N loading condition, 50N (100 hours), 50N (300 hours) and 50N (400 hours). These acquired sound signals were analysed using appropriate signal processing techniques such as FFT and CWT to correlate the condition of the gearbox.

Acquired sound signals under different conditions are stored in time-domain format for analysis. FFT converts the

Table 1: Specifications of spur gear

	Parameters	unit	Gear	Pinion
1	Number of teeth		45	28
2	Module	mm	2.5	
3	Pressure angle	degree	20	
4	Face width	mm	25	
5	Centre distance	mm	91.25	
6	Pitch circle diameter	mm	112.5	70
7	Max. allowable stress	MPa	448	
	Composition of gear material			
8	Material (EN24 steel alloy)	En24, 0.4% C, 0.225% Si, 0.575% Mn 1.2% Cr, 1.5% Ni		

given signal from the time domain to the frequency domain by integrating the given function over the entire time period. The details of Fourier transform for the angular frequency and time can be seen in[6,7].

Wavelet analysis is one of the 'time-frequency' analyses. A wavelet is a basis function characterized by two aspects; the first is its shape and then its amplitude, which is chosen by the user, second is its scale (frequency) and time (location) relative to the signal. The continuous wavelet transform can be used to generate spectrograms that show the frequency content of signals as a function of time. The detailed explanation about CWT technique can be seen in [6 and 8].

3.0 Results and Discussion

The collected sound signals are analysed by using FFT and CWT signal processing technique.

3.1 Time Domain Analysis

The time domain graph is plotted by taking time along x-axis and amplitude along y-axis. Time domains corresponding to different conditions are shown in Figures 3 to 7.

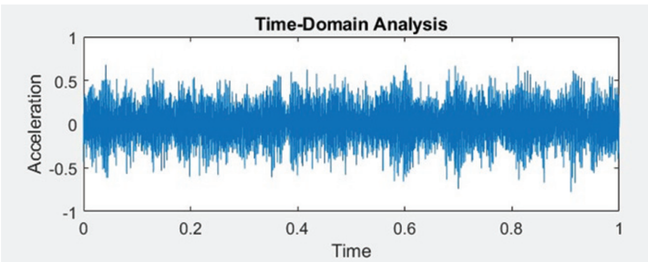

Figure 3: Time-domain plot for no load condition

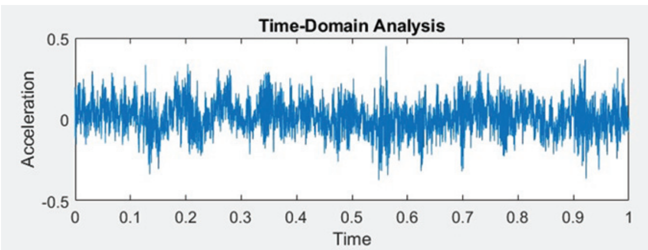

Figure 4: Time-domain plot for 50N condition

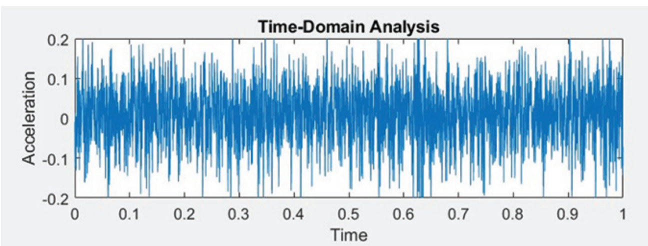

Figure 5: Time-domain plot for 50N condition after 100 hours

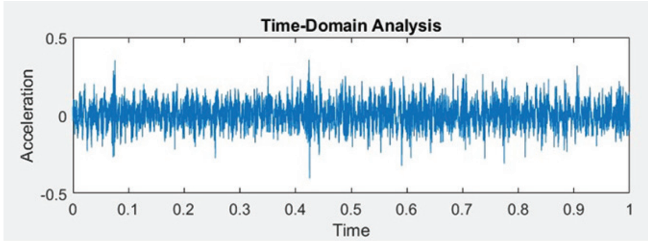

Figure 6: Time-domain plot for 50N condition after 300 hours

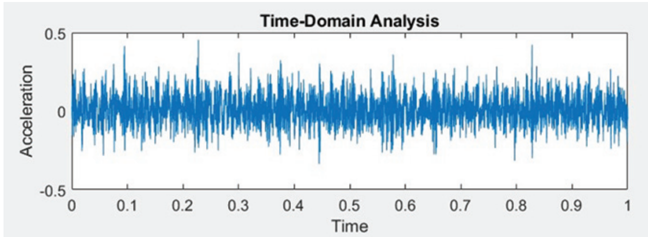

Figure 7: Time-domain plot for 50N condition after 700 hours

It can be seen that, the amplitude of the signal fluctuates over the time period for different conditions. However, only minute variations in the amplitude pattern are seen. So, it becomes very difficult to monitor the gear box condition.

3.2 Frequency Domain Analysis

The above time domain graphs are converted to frequency domain as shown in the Figures 8 to 12.

The gear is rotating at 600 rpm with frequency, whereas the pinion rotates at 964 rpm. By observing the frequency domain graphs, it can be seen that the dominancy is shown as 800Hz when compared to other frequency. This 800 Hz

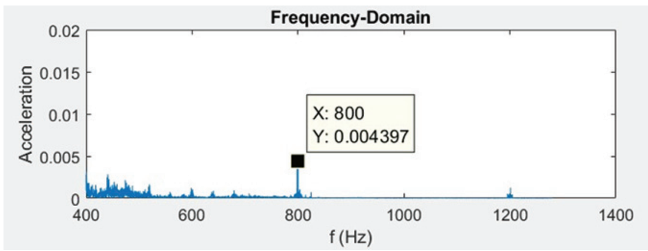

Figure 8: Frequency-domain plot for no load condition

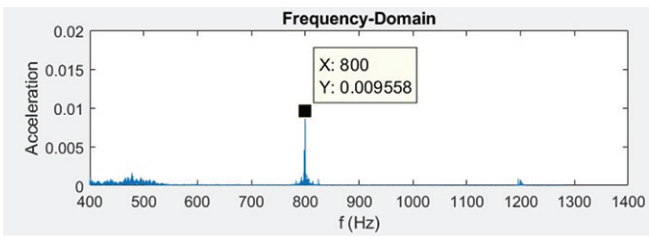

Figure 9: Frequency-domain plot for 50N condition

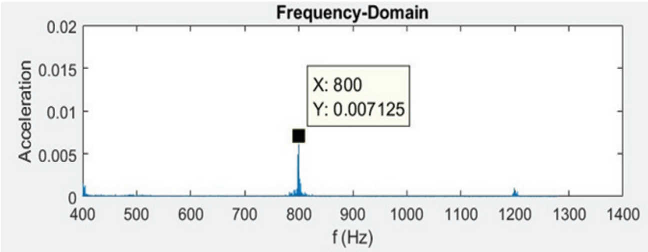

Figure 10: Frequency -domain plot for 50N condition after 100 hours

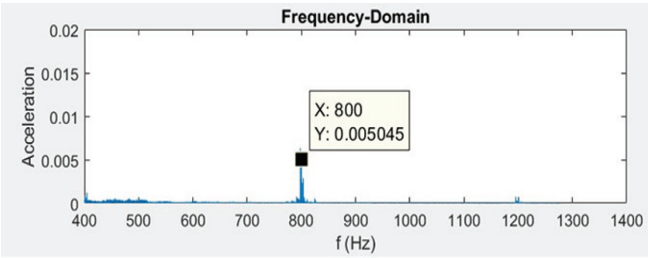

Figure 11: Frequency -domain plot for 50N condition after 300 hours

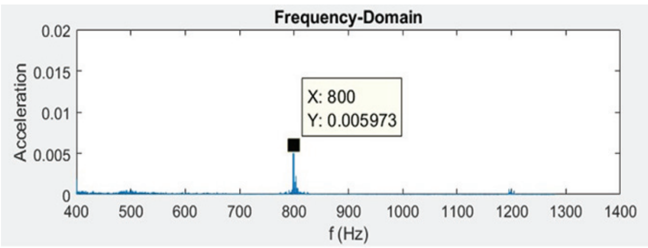

Figure 12: Frequency -domain plot for 50N condition after 400 hours

appearing at 50th multiple of pinion rotation frequency. The pinion is having a frequency of 16Hz. The spectrum of plot of the rotation frequency of pinion along with its harmonics, the peaks are found at different loading conditions. This can be easily seen by carrying out FFT analysis where loading gear conditions are seen to show higher amplitude when compared to no load gear conditions.

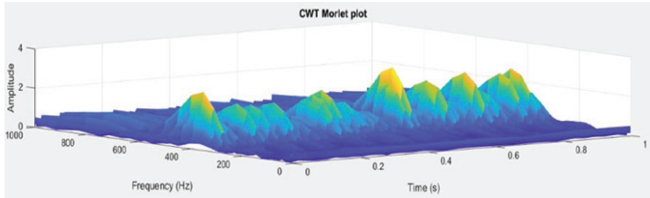

Figure 13: CWT plot for no load condition

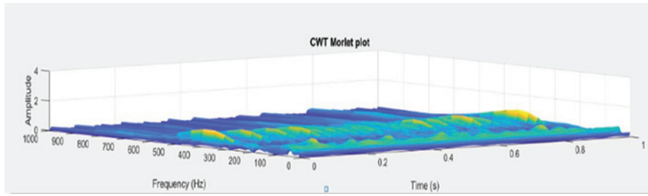

Figure 14: CWT plot for 50N load condition

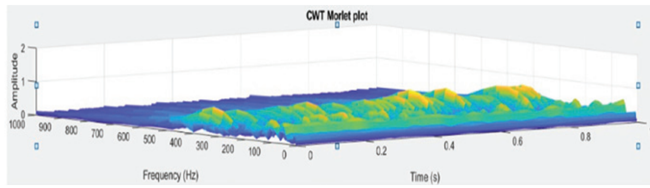

Figure 15: CWT plot for 50N condition after 100 hours

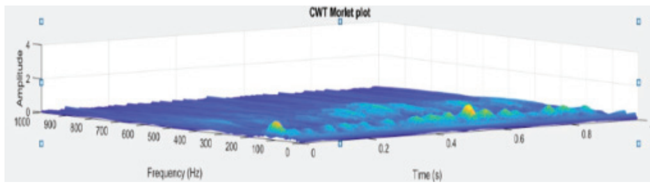

Figure 16: CWT plot for 50N condition after 300 hours

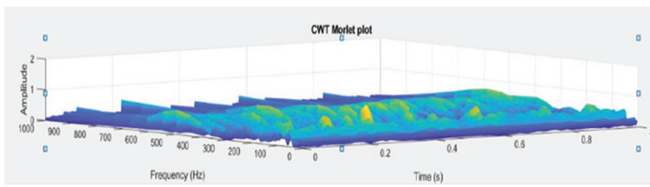

Figure 17: CWT plot for 50N condition after 400 hours

3.3 CWT Analysis

Wavelet analysis is one of the most effective and efficient signal processing technique as both stationary and non-stationary signals are handled by it. Here 3D graphs are obtained and we can plot amplitude, time and frequency at the same time as shown in Figures 13 to 17.

In the above graphs, The CWT plots are various gear box conditions are seen. We can see the dominancy at 50^{th} multiple of rotational frequency of pinion.

4.0 Conclusion

Sound analysis has been shown to be a very effective techniques to monitor the condition of the gearbox. In this paper, we have considered FFT and CWT techniques to analyse the sound signals for different gear conditions. Time domain plot does not provide diagnostic information for different gear conditions. The use of spectral analysis to examine basic frequency content and dominant frequency in the spectrum is a promising technique. Along with FFT, the CWT technique is an advanced technique applied to understand the condition of the gearbox. Hence these techniques can be preferred in the area of condition monitoring.

5.0 References

1. Ahmaida, A., Zhen, D., Gu, F., and Ball, A. (2014): Gear wear process monitoring using acoustic signals.
2. Baydar, N., and Ball, A. (2003): Detection of gear failures via vibration and acoustic signals using wavelet transform. *Mechanical Systems and Signal Processing,* 17(4): 787-804.
3. Feng, K., Smith, W. A., Randall, R. B., Wu, H., and Peng, Z. (2022): Vibration-based monitoring and prediction of surface profile change and pitting density in a spur gear wear process. *Mechanical Systems and Signal Processing,* 165: 108319.
4. Jing, L., Zhao, M., Li, P., and Xu, X. (2017): A convolutional neural network based feature learning and fault diagnosis method for the condition monitoring of gearbox. *Measurement*, 111: 1-10.
5. Vecer, P., Kreidl, M., and Smíd, R. (2005): Condition indicators for gearbox condition monitoring systems. *Acta Polytechnica,* 45(6).
6. Vernekar, K., Kumar, H., and Gangadharan, K. V. (2014): Gear fault detection using vibration analysis and continuous wavelet transform. Procedia Materials Science, 5: 1846-1852.
7. Madhusudana, C. K., Kumar, H. and Narendranath, S. (2016): Fault detection of face milling cutter through spectrum, cepstrum and wavelet analysis. *Journal of Vibration Analysis, Measurement, and Control*, 4(1):10-28.
8. Ravikumar, K. N., Madhusudana, C. K., Kumar, H. and Gangadharan, K. V. (2020): Ball bearing fault diagnosis based on vibration signals of two stroke ic engine using continuous wavelet transform. In Advances in Rotor Dynamics, *Control, and Structural Health Monitoring* : 381-391).