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Wavelet Analysis of Vibration Signature of a Bevel Gear Box in a Stand of Steel Rolling Mill of a Steel Plant

Md. Faridha Khanam[1], P. Ravi Kumar[2], Dr. D. Srinivasarao[3]

1 M.Tech. Student, 2 Assistant Professor, Department of Mechanical Engineering, PVP Siddhartha Institute of Technology, Vijayawada, Andhra Pradesh, India

3 Professor, Department of Mechanical Engineering, DMS SVH College of Engineering, Machilipatnam, Andhra Pradesh, India

Abstract: *In manufacturing industry Gear boxes are one of the important components in power transmission. Consequently any damage in the gearbox can lead to unprecedented downtime. In machines the gear trains vibrate due to many reasons such as the non regular nature of load, the manufacturing error of the gear teeth, gear back lash, misalignment of the connecting shaft and also due to continuous usage. As a common rule machines do not stop working or fail without some form of caution, which is indicated by an increased vibration level. The most effective instruments which are used in reading the root cause of the trouble are the Vibration analyzers, which collects the vibration signature at the problematic source. In the present work the vibration analysis of bevel gear box in a vertical rolling stand of Light and Medium Merchant Mill (LMMM) at Vizag steel plant is considered for the purpose of condition monitoring. The vibration signatures of input and output shafts of bevel gear box in vertical, horizontal and axial directions are collected at input and output shafts of the gear box using Vb8 instrument. The signatures so collected were further analyzed using wavelet analysis. The analysis is carried out at no-load and loaded conditions at regular intervals of operation for monitoring the gear box and results are discussed.*

Keywords: *Bevel gear box, MATLAB, Vibration Signature, Wavelet Analysis,*

I. Introduction

In manufacturing industry the crucial power transmission components are gears they are very robust in operation and extremely dependable. The vibration in gear trains causes due to alteration of external load, error of gear teeth during manufacturing, impact meshing, error in shape of gear teeth profile and gear backlash due to wearing. The power transmission between intersecting shafts can be accomplished using bevel gears, they can function at high loads and speeds with considerable precision rating. The better option for the usage of Bevel gears is for right angle drive of low velocity ratios extensive application of straight Bevel gear drives points in automotive differentials, right angle drives or conveyors

The health of rotating machinery is dynamically determined by means of a consistent method termed as periodic vibration monitoring [1].Generally machinery problems can be isolated and detected earlier by the process of analysis of overall vibration levels and associated vibration frequency signatures. Along with other problems imbalance, improper clearances, mechanical looseness, misalignment and anti-friction bearing defects are some included. This early detection allows corrective maintenance to be prioritized and scheduled during non-critical periods, resulting in increased machinery availability and significant savings in both replacement parts and labor costs [2].Therefore the risk of premature failure diminished and the production is also maximized.

Industrial practice equipment normally in service speeds ranging from several 100's to nearly 20000rpm. Which are generally rated more than 100KW Vibration data and vibration frequency signatures collected, processed and analyzed using vibration analyzer's assists the maintenance engineer to identify the faults associated with machinery components as a part of prognostic maintenance system [2]. Historical information or spectral data cannot be obtained by offline monitoring system and hence most of the crucial machinery requires permanently established vibrating monitoring systems [3].

At Vizag Steel Plant steel blooms of cross section(320mmx320mm) are wrecked into billets of cross section(125mmx125mm) each in Light Medium Merchant Mill(LMMM) these billets are then turn rolled into rounds, re bars ,angles and channels correspondingly. These billets are also supplied as input to the Wire Rod Mill(WRM).The LMMM steel plant consists of 7 rolling stands for the above mentioned purpose some of them are horizontal rolling stands and remaining are vertical each vertical stand consists of a prime mover(motor), bevel gear box, transmission shaft, and a top gear box. The of output top gear box supply power to the two vertical rollers and ensure that both rollers rotate at constant speed and avert the slippage of the hot steel ingot. The present work main emphasis is given to identify the fault by vibration signature analysis of the gear box using wavelet analysis.

II. Wavelet Transform

Signal Analysis of Vibration Data – Key for Fault Detection & Monitoring. Signals with sharp sudden changes could be better analyzed with an irregular and asymmetric wavelet than with a smooth sinusoid. Wavelets have limited duration that has an average value of zero.

Wavelets are functions that satisfy certain mathematical requirements and are used in representing data or other functions. This idea is not new. Approximation using superposition of functions has existed since the early 1800's, when Joseph Fourier discovered that he could superpose sines and cosines to represent other functions. However, in wavelet analysis, the scale that we use to look at data plays a special role. Wavelet algorithms process data at different scales or resolutions. If we look at a signal with a large "window, we would notice gross features. Similarly, if we look at a signal with a small "window," we would notice small features. The result in wavelet analysis is to see both the forest and the trees, so to speak.

This makes wavelets interesting and useful. For many decades, scientists have wanted more appropriate functions than the sines and cosines which comprise the bases of Fourier analysis, to approximate choppy signals. By their definition, these functions are non-local (and stretch out to infinity). They therefore do a very poor job in approximating sharp spikes. But with wavelet analysis, we can use approximating functions that are contained neatly in finite domains. Wavelets are well-suited for approximating data with sharp discontinuities.

The wavelet analysis procedure is to adopt a wavelet prototype function, called an analyzing wavelet or mother wavelet. Temporal analysis is performed with a contracted, high-frequency version of the prototype wavelet, while frequency analysis is performed with a dilated, low-frequency version of the same wavelet. Because the original signal or function can be represented in terms of a wavelet expansion (using coefficients in a linear combination of the wavelet functions), data operations can be performed using just the corresponding wavelet coefficients. And if you further choose the best wavelets adapted to your data, or truncate the coefficients below a threshold, your data is sparsely represented. This sparse coding makes wavelets an excellent tool in the field of data compression. Mother wavelet is a prototype for generating the other window functions.All the used windows are its dilated or compressed and shifted versions.

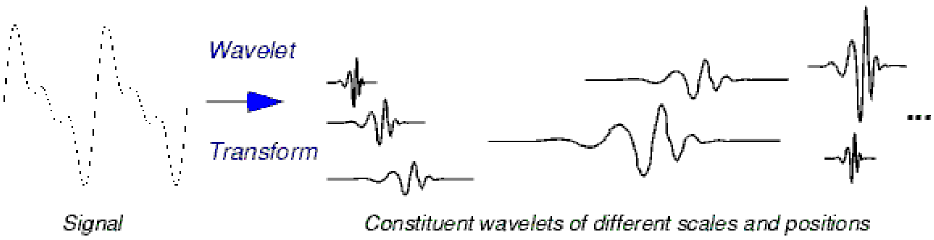

Figure 1: Description of wavelet transform

Signal broken into a series of local basis functions called wavelets, which are scaled and shifted versions of the original (or Mother) wave let**.** Wavelet transforms are most broadly classified into the discrete wavelet transform (DWT) and the continuous wavelet transform (CWT). The DWT is used for signal coding whereas the CWT is used for signal analysis. Consequently, the DWT is commonly used in engineering and computer science and the CWT is most often used in scientific research. In this project work continuous wavelet transform (CWT) is used.

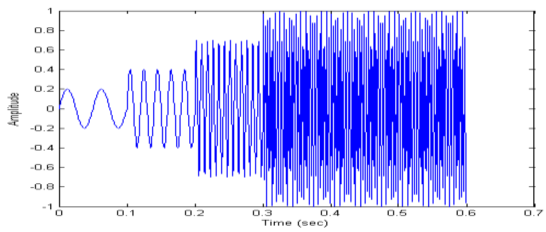

Figure 2: Example of Continuous wavelet Transform

2.1. Functions of Wavelet Transform

1. Convert a signal into a series of wavelets.
2. Provide a way for analyzing waveforms, bounded in both frequency and duration.

3. Allow signals to be stored more efficiently than by Fourier transform.
4. Be able to better approximate real-world signals.
5. Well-suited for approximating data with sharp discontinuities.

2.2. Scaling (S)

S > 1 dilate the signal

S< 1 compress the signal.

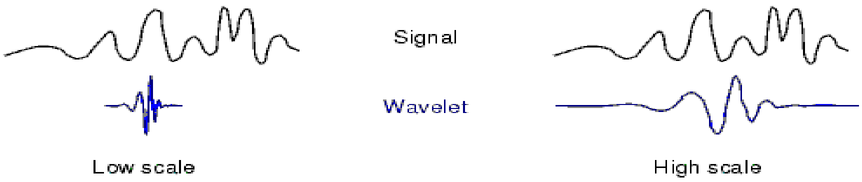

Figure 3: Scaling

1) Low Scale -> High Frequency -> Detailed View Last in Short Time..
2) High Scale -> Low Frequency -> Non-detailed Global View of Signal -> Span Entire Signal.
3) Only Limited Interval of Scales is Necessary.

2.3. Wavelet Applications

Typical Application Fields

Astronomy, acoustics, nuclear engineering, sub-band coding, signal and image processing, neurophysiology, music, magnetic resonance imaging, speech discrimination, optics, fractals, turbulence, earthquake-prediction, radar, human vision, and pure mathematics applications. Some of the typical applications are

1) Identifying pure frequencies.
2) De-noising signals.
3) Detecting discontinuities and breakdown points.
4) Detecting self-similarity.

III. Problem Depiction And Experimentation

The layout of vertical stand 5 LMMM is shown in “Fig.4”, in which the gear unit transmits motion from motor to top gear box. The main function of it is to afford variation in speed and torque and also change of the direction of the flow. The bevel wheels are made from case-hardened steel. The teeth of the wheels are case-hardened and lapped. The input and output shafts are mounted with spherical roller bearing(23234C3),Cylindrical roller bearing(NU-232) and 4-point thrust bearing(QJ 232)[4].The necessary contact pattern of gear mesh and adjustment of backlash are done via a set of collar rings provided with the input shaft system as shown in “Fig .5”.

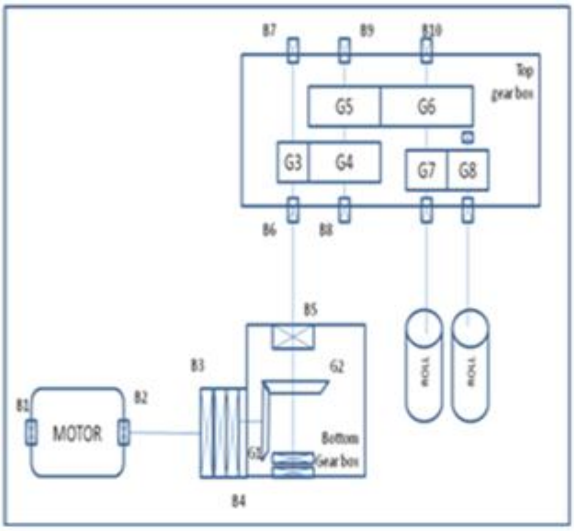

Figure 4: Layout of stand in LMMM

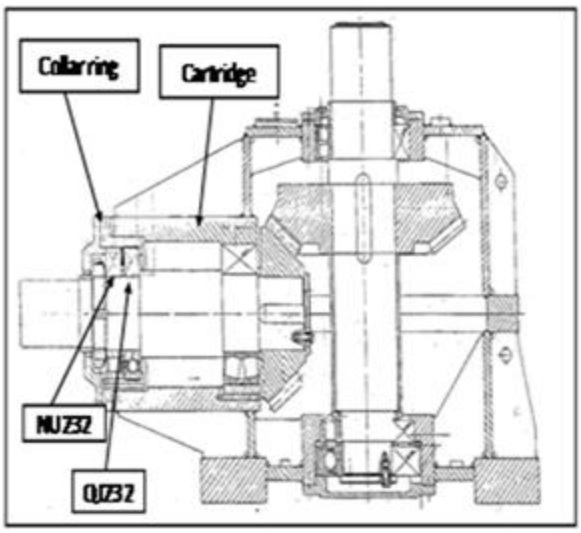

Figure 5: Arrangement of bottom bevel gear box

3.1 Specifications of bottom gearbox

Motor Speed: 440-880 rpm
Weight: 2805 kgs
Gear teeth: 22/33
Normal output torque: 24.36 kN-m

motor rating: 1100 kW
Oil pressure: Min =1.2 bar, Max= 1.8 bar
Design root clearance: 0.50 mm
Design Back lash: 0.33 mm

Installation of a new indigenous bottom bevel gear box was done at stand 5 on 13/2/2014. The velocity vibration signatures were collected in vertical, horizontal and axial directions at different intervals in loaded and unloaded conditions of the gear box at input side and output side using Vb8 instrument. These signatures for both damaged and undamaged condition are shown from “Fig. 6” to “Fig. 11”.The signatures so obtained were further subjected to wavelet transform, a powerful signal processing technique available with MATLAB using “SYM2” wavelet. The wavelet coefficients obtained at different scales are shown from “Fig. 12” to “Fig. 17”. The vibration signature of the stand at various predefined points has been constantly examined to establish by usual functioning of the gear box. On incessant monitoring it has been observed that there is a continuing augmentation in the overall RMS velocity value of the vibration signature. It is observed a significant increase in radial component of input side of the bottom gearbox.

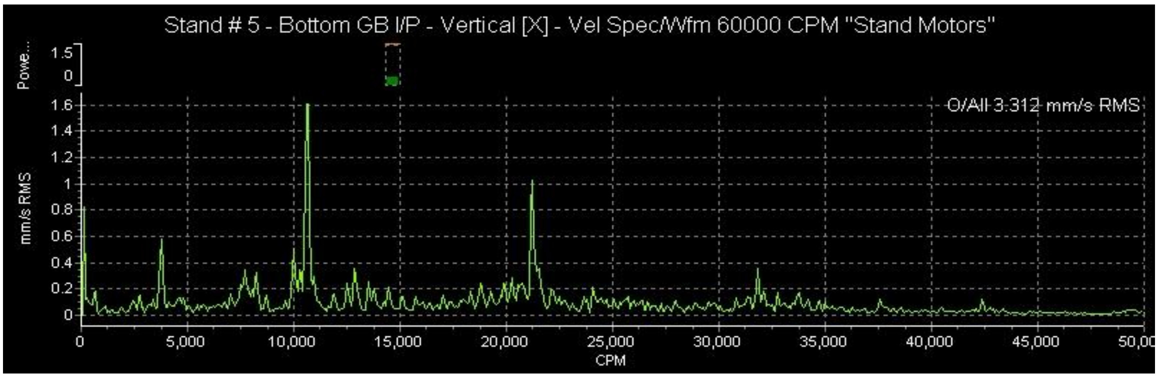

Figure 6: Vibration spectrum at input side of BGB in vertical direction in damaged condition.

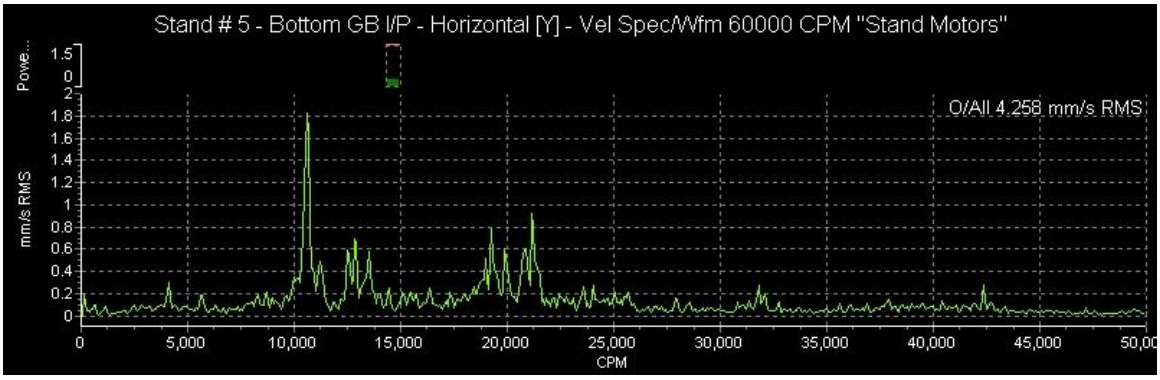

Figure7: Vibration spectrum at input side of BGB in horizontal direction in damaged condition.

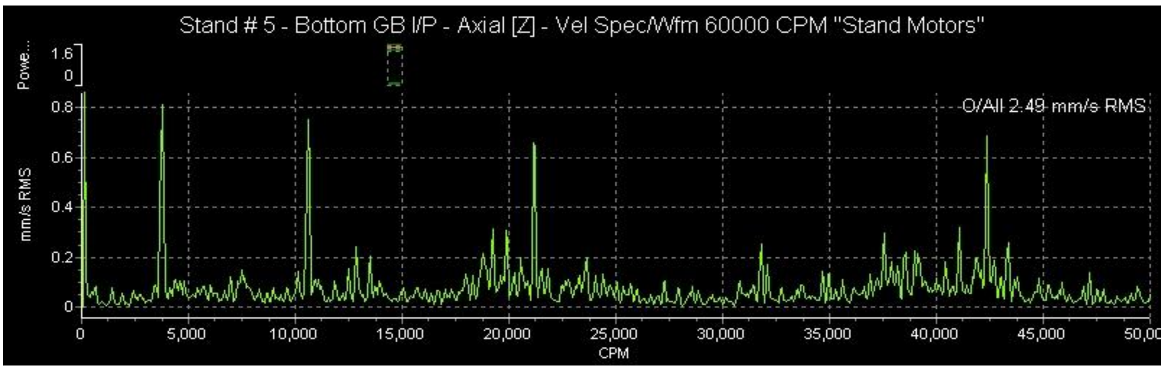

Figure 8: Vibration spectrum at input side of BGB in axial direction in damaged condition.

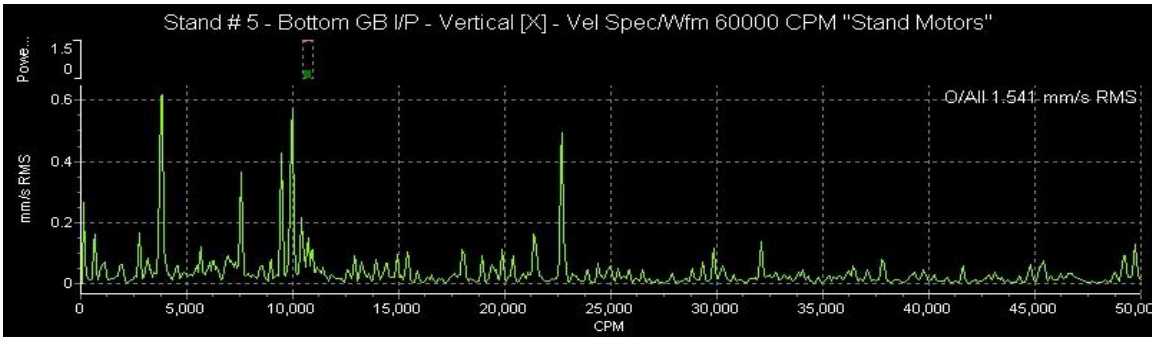

Figure9: Vibration spectrum at input side of BGB in vertical direction in undamaged condition.

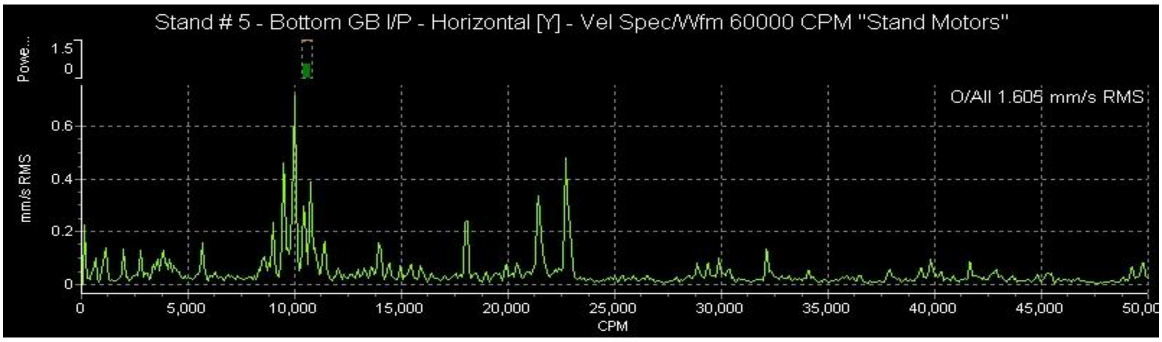

Figure10: Vibration spectrum at input side of BGB in horizontal direction in undamaged condition.

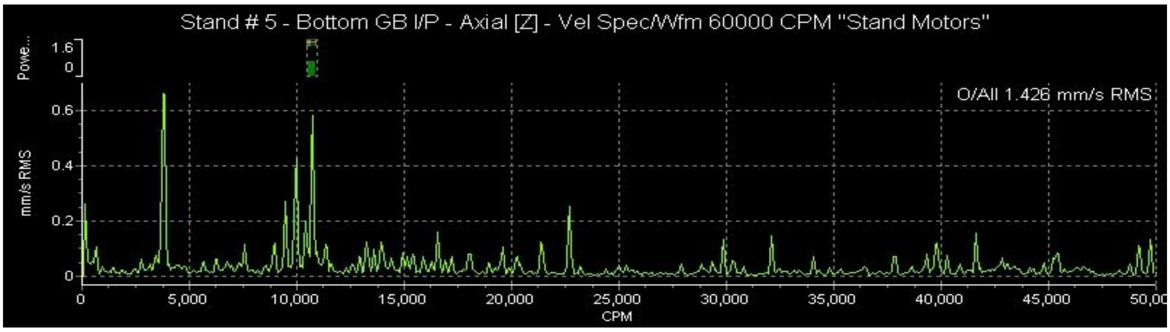

Figure 11: Vibration spectrum at input side of BGB in axial direction in undamaged condition.

IV. Results And Discussion

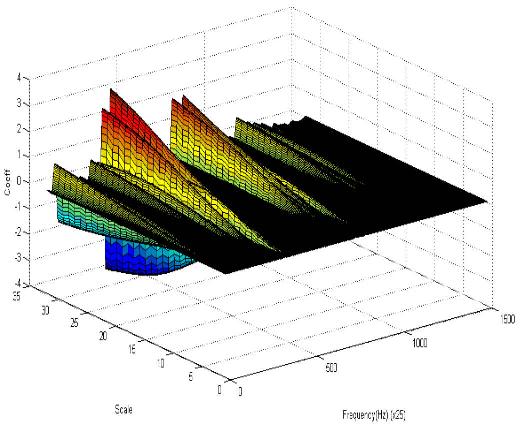

Figure 12: Wavelet coefficients of vertical vibration spectrum at input side of BGB in damaged condition

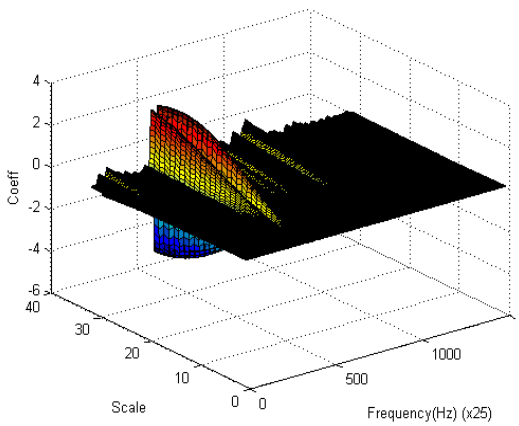

Figure13: Wavelet coefficients of horizontal vibration spectrum at input side of BGB in damaged condition

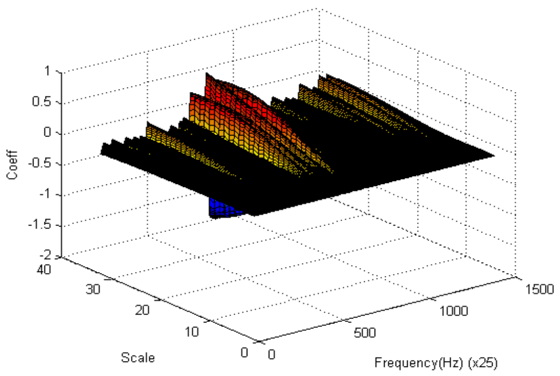

Figure14: Wavelet coefficients of axial vibration spectrum at input side of BGB in damaged condition

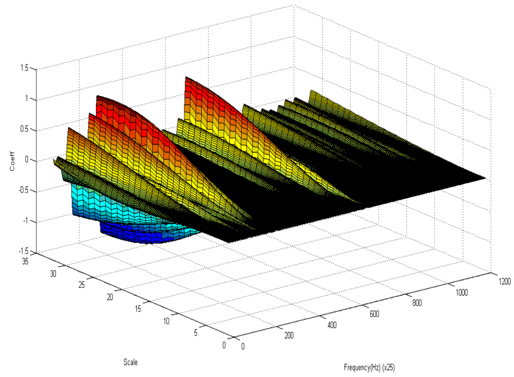

Figure15: Wavelet coefficients of vertical vibration spectrum at input side of BGB in undamaged condition

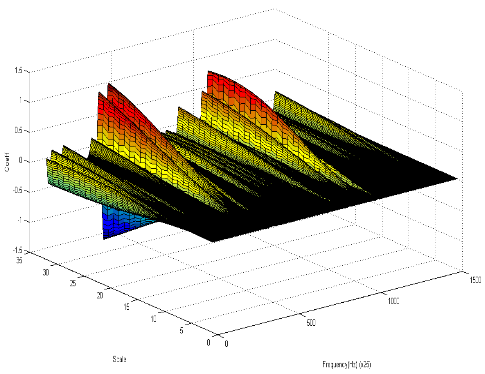

Figure16: Wavelet coefficients of horizontal vibration spectrum at input side of BGB in undamaged condition

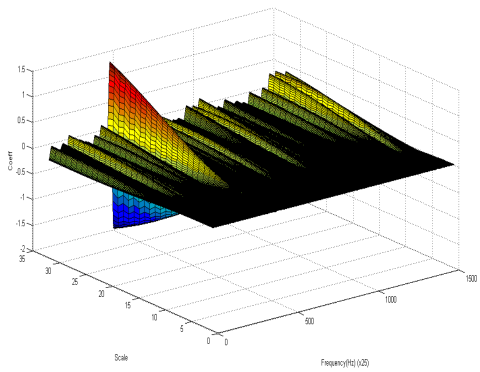

Figure17: Wavelet coefficients of horizontal vibration spectrum at input side of BGB in undamaged condition

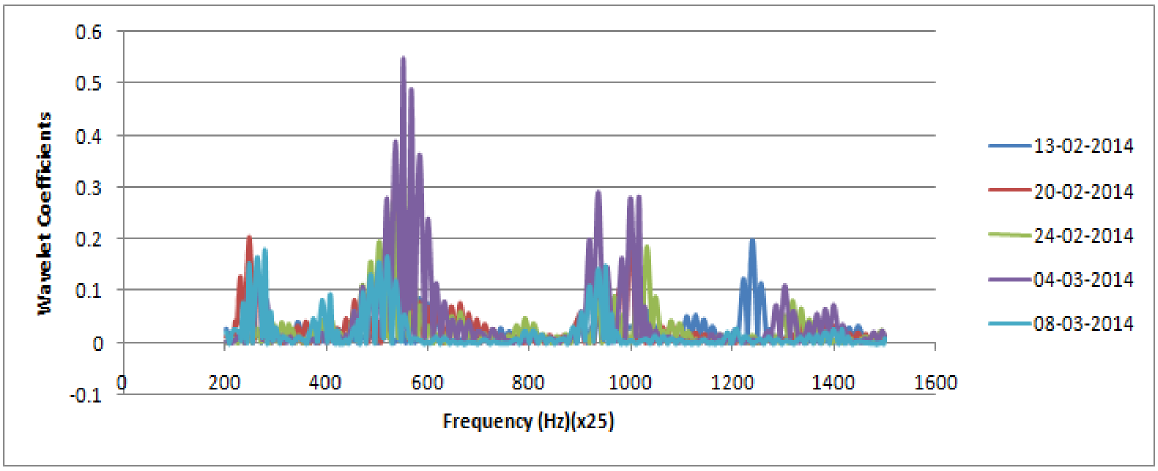

Figure18: Frequency versus wavelet coefficients of vertical signature at various time intervals for scale 8

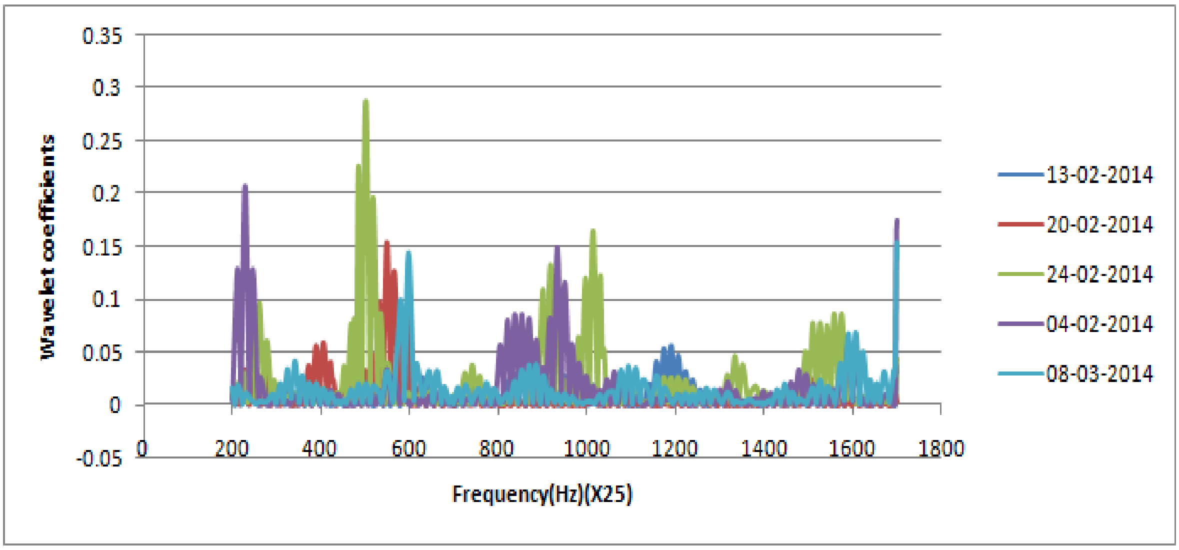

Figure19: Frequency versus wavelet coefficients of horizontal signature at various time intervals for scale 8

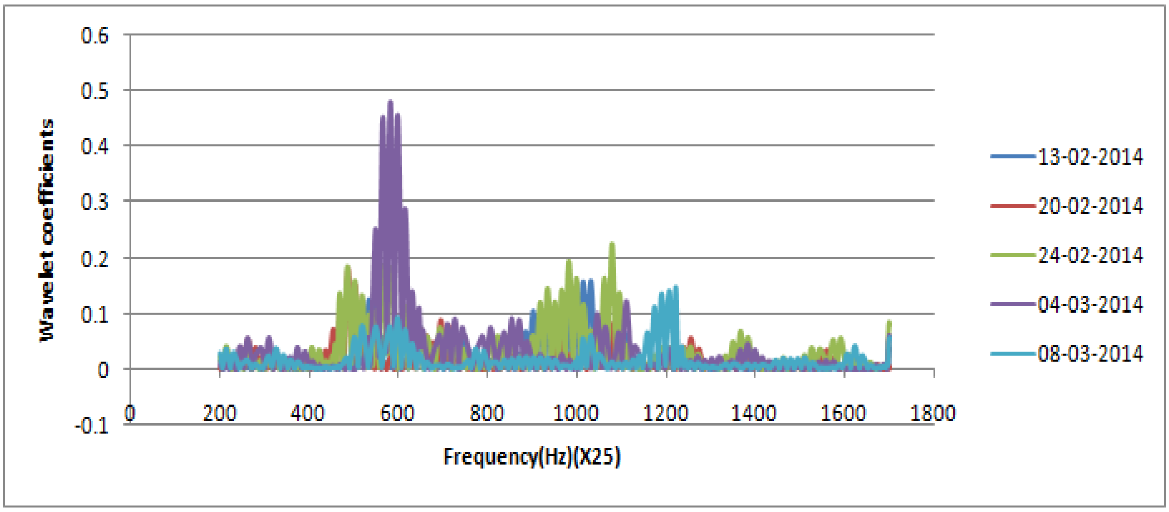

Figure20: Frequency versus wavelet coefficients of axial signature at various time intervals for scale 8

The performance of the gear box was observed form date of installation to date of severe damaged condition. i.e., from 13/02/2014 to 04/03/2014.During these periods of operation in general loaded condition the performance is as shown in the "Fig 12" to "Fig.20". The wavelet coefficients of vibration signatures of three directions are shown in form "Fig.18" to "Fig.20" at 'scale 8'.The wavelet coefficients show significant values for the vertical vibration signature in damaged condition. This can be observed in "Fig.18" which was drawn for a particular 'scale 8'for severely damaged condition on 04/03/2014. The gear box shaft alignment test was also carried out to ascertain any misalignment of the gearbox input shaft. But the alignment test results ruled out the possibility. In the gear box assembly a collar ring and a cartridge are provided so that the contact pattern of the meshing gears can be alter as per requirement. The bearing is seated upon the cartridge .Actually an interference fit is to be present between the outer race of the bearing and inner periphery of the cartridge. The concentricity of the gear meshing can be affected by any sort of disorder in cartridge/bearing interferences which could result in misalignment of gears. Hence the gear misalignment was suspected due to cartridge as the temperature of casing has raised to 85^0C against normal operating temperature of 65^0.After dismantling the dimensions of the cartridge and bearing outer diameter were measured and compared with drawing (Table 1).

Table1: Dimensions of cartridge, bearing

S. No	As per drawing		After dismantling	
1	OD of Bearing(mm)	ID of Cartridge(mm)	OD of Bearing(mm)	ID of Cartridge(mm)
2	290	$290.0^{-0.02}$	290	290.05

The revealing of incorporation of transition fit during assembly, in place of interference fit between cartridge-bearing interface was done by the indigenous gearbox supplier when the design parameters were traced back to them. An interference fit was supposed to be provided at the particular zone. During operation of the gear box under loaded condition the continuous load cycle must have brought the fit from transition to clearance zone. The cartridge was replaced and the vibration readings of the rectified gear box can be ascertained from the wavelet coefficients of vibrations signatures taken on 08/03/2014 which were also shown in "Fig 18" to "Fig.20".

V. Conclusion

Analyzing the cartridge dimensions after dismantling the gearbox, it illustrated that there is an increase in the diameter of the cartridge which introduced looseness in between bearing outer race and the cartridge. On re-tracking the installation parameters of the subject gearbox from the supplier, it was found out that a transition fit has been achieved at the input bearing as against an interference fit. Continuous cyclic nature of load resulted in the fit to go into the clearance fit range gradually, which further got augmented and resulted in high vibrations of the shaft. It is proposed to procure a test rig to perform tests on newly purchased gear boxes to run for 2 – 3 days to demonstrate their fault proof operation. Wavelet analysis of Vibration signatures can be considered as a powerful tool in fault diagnosis in any industry and can reduce unnecessary overheads in terms of breakdowns and manpower costs.

Acknowledgements

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