iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 7 **Issue:** VI **Month of publication:** June 2019

DOI: http://doi.org/10.22214/ijraset.2019.6339

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.177
Volume 7 Issue VI, June 2019- Available at www.ijraset.com

Vibration Response of a Gearbox having Gear with Teeth Root Cracks

Nouman Khan[1], Ajit Prasad S L[2]
[1]M.Tech Scholar, [2]Professor, PES College of Engineering, Mandya,

Abstract: Gear defects are the major sources of vibration in the gearbox. In gear defects, tooth fracture is the most serious fault in gearbox and it may cause complete failure of the gear. Early detection of the tooth crack is helpful in avoiding the disastrous breakdown of the gearbox. The present work is an attempt to investigate the vibration characteristics of the gearbox, which has cracked gear as the defect. Vibration signals are acquired using accelerometer placed on the bearing housing nearer to the gear pair. FFT spectrum and order tracking analysis are useful tools for the monitoring of machinery vibration. The gear mesh frequency in the FFT analysis and the sidebands in the vibration signal are useful in the gearbox fault diagnosis. Comparison is made between the signals of healthy gear and faulty gear at various speed and load conditions and analysis of the signals show distinct differences in the vibration characteristics between healthy and faulty gear systems.
Keywords: Vibration, Gear mesh frequency, Order.

I. INTRODUCTION

Rotating machines are among the most commonly used mechanical equipments and play a significant role in industrial applications such as wind turbines, high speed trains, aircraft engines etc. Timely/early detection of defects developing in rotating machines is extremely important to ensure equipment safety, reduce maintenance costs and improve production efficiency. Gearboxes are one of the most prevalent components in rotating machines and often operated in harsh conditions. Thus minor failure such as a micro crack sometimes cause mechanical equipment to breakdown quickly and may cause catastrophic accidents [1].Gears drive efficiency is significantly higher than any other mechanical, electrical, pneumatic power transmission drives and they are highly used in transforming rotational motion and speed control but some faults always occur on the gears because of the continuous running [2]. Since gear operation condition directly affects the working state of mechanical equipment, identification of gear faults in the early stage has great economic significance and will obviously improve the reliability of machine. Hence condition monitoring of mechanical systems is a necessity [3].

Vibration based technique have been successfully applied to machine health monitoring, fault detection and diagnostics. Vibration signals acquired from the gearbox casing are used for analysis and this is the most modern techniques for fault diagnosis of gearbox [4]. The presence of various types of faults at earlier stage and their evolution are detected in order to analyze the machine's residual life and select a proper plan of maintenance [5]. The foremost imperative component in vibration spectra is the gear mesh frequency [Gear mesh = Number of teeth x Shaft speed] with its harmonics and sidebands around it. The fault condition may alter the amplitude and number of sidebands. The sidebands are the frequency components organised equally around the gear mesh frequency which is the center frequency[6]. The defects such as, cracks localized on one tooth or a few teeth produce modulation effects during the engagement of the defect teeth. Subsequently, a large number of side bands of the gear mesh frequency and its harmonics in the spectrum are generated and they are spaced by the rotation frequency of the fault gear [7].

Order tracking technique has become one of the important methods for fault diagnosis in rotating machinery. Vibration signals produced from rotating machinery such as Gearbox are dependent on speed and hence orders are preferred as the frequency base. Orders represent the number of cycles per revolution and are ideal for representing speed dependent vibrations. Hence, order tracking technique normally uses a vibration signal supported with the information of shaft speed for fault diagnosis of gearbox. The order spectrum gives the amplitude of signal as a function of shaft speed in rotating machinery [8].

Power transmitting gear teeth are subjected to repeated bending load. Gear teeth are prone to failure at the root since maximum bending stress as well as stress concentration occurs at the root. Failure can initiate as minute crack at the root and can propagate with repeated loading, leading to tooth breakage. Hence it is essential to detect the root crack at initial stages in order to prevent tooth breakage. The present work is a small attempt to study the vibration response of a gearbox having gar with tooth root cracks.

II. METHODOLOGY

Back to back or power recirculating type of gear test rig has been used to carry out the vibration analysis of gearbox in the present work. The tooth root crack in a gear tooth is cut to emulate a real crack by wire electric discharging machine (wire-cut EDM). The vibration signals of the gearbox systems both with perfect teeth and root-cracked tooth are acquired at different speed and torque conditions and are subsequently analyzed under frequency spectrum analysis in time domain and frequency domain respectively. From the FFT analysis results, the vibration features of the cracked gear are acquired and comparisons are made between the healthy condition and defective condition of the gear.

Figure 1: Schematic Representation of Gearbox Test Rig

Fig-1 shows the Gearbox test rig used in the present work. The Gearbox test rig consists of a Test gear pair and a Master or Slave gear pair. Both the Test gear pair and the Master gear pair consists of spur gear pair having the teeth ratio as 45/28. The load is applied onto the load coupling assembly using the loading arm. The specifications of the Gear pair used in the present work are given in table-1.

TABLE 1
Specifications of gear pair

SL.NO.	Parameter	Gear	Pinion
1	Material	Mild Steel	Alloy 20MnCr5
2	Number of Teeth	45	28
3	Module (mm)	2.5	
4	Pressure Angle (deg)	20	
5	Face Width (mm)	25	
6	Pitch Circle Diameter (mm)	45*2.5=112.5	28*2.5=70
7	Center distance (mm)	91.25	

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.177
Volume 7 Issue VI, June 2019- Available at www.ijraset.com

Operating parameters selected in the present work, are shown in table- 2 and Gear designations in table-3.

TABLE 2
Operating parameters

SL. NO.	Operating parameters	Value
1	Torque (N-m)	0, 07.85, 19.62 and 39.24
2	Speed (rpm)	200 -800, in steps of 200

TABLE 3
Gear designations

Healthy Gear	H
Gear with one cracked tooth	F1
Gear with two cracked teeth	F2
Gear with four cracked teeth	F3

Three different faulty gears are shown in fig-2.

a) F1 b) F2 c) F3

Figure 2: Different type of faulty gears

Frequency response function (FRF) analysis is carried out to estimate modal parameters of the gear box by conducting impact hammer test. Vibration measurement is carried out by using uniaxial accelerometer which is placed in vertical (radial) direction near the bearing housing of the gearbox. Raw vibration signals collected in the time domain are converted into frequency domain by carrying out Fast Fourier Transformation (FFT) of collected signals. The vibration characteristics obtained from time domain and frequency domain signals and order tracking analysis are used for assessing the condition of the gear.

III. RESULTS AND DISCUSSION

A. Frequency response function (FRF)

FRF (Frequency Response Function) is used to find the natural frequencies of a system by using impact hammer method.

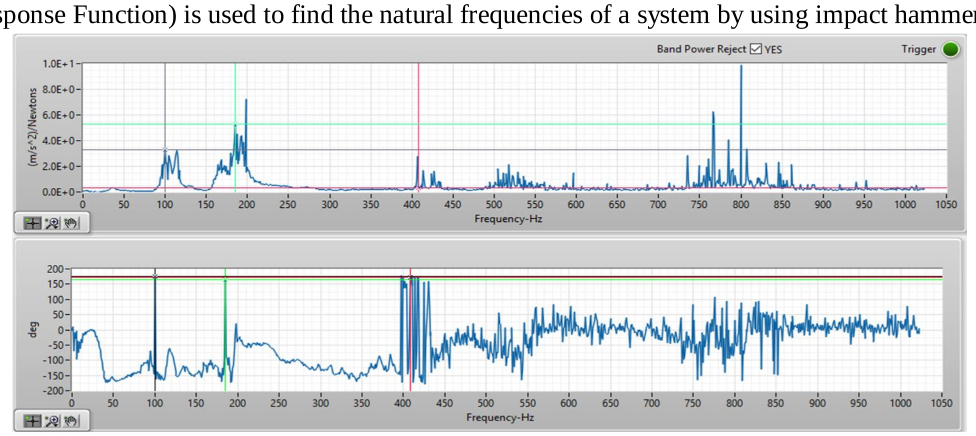
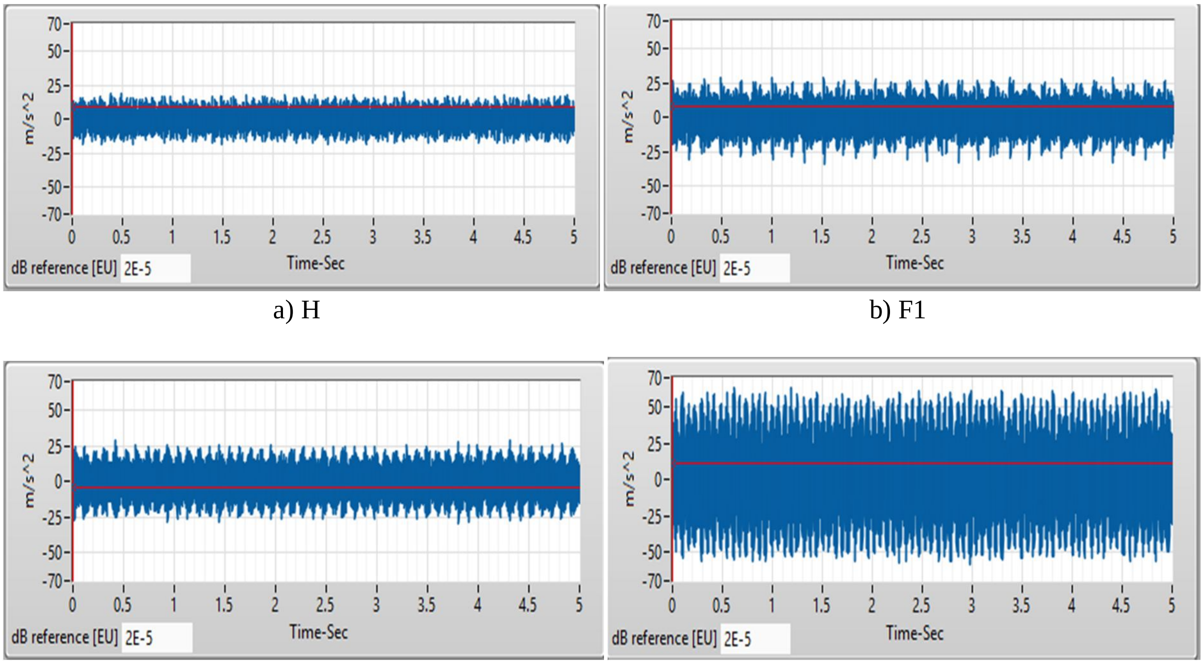


Figure 3: FRF of the Gearbox

Fig-3 shows FRF signal obtained from impact hammer test of the gearbox. The First three Gear Natural Frequencies obtained from the FRF analysis are 100Hz, 185HZ and 408Hz.

B. Time Domain Analysis

The time domain signals of gearbox for healthy and faulty gears are shown in fig-4.



a) H b) F1

c) F2 d) F3

Figure 4: The time domain signals of gearbox casing for healthy and faulty gears

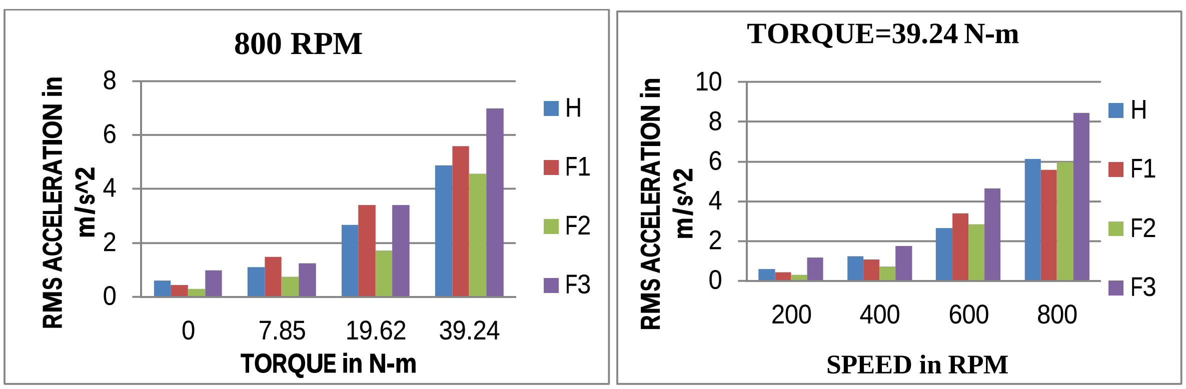
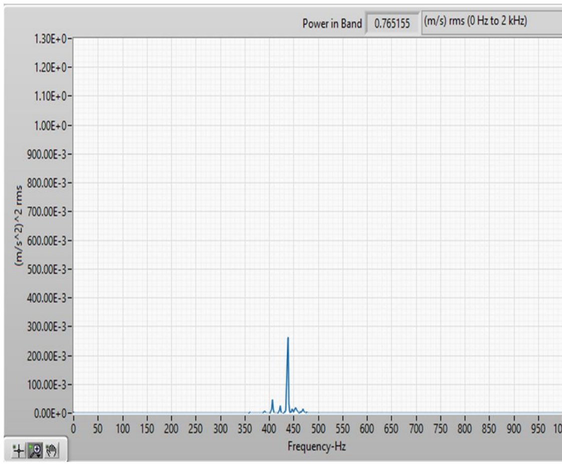


Figure-5: Comparison of RMS value for healthy and faulty Gear box for various speed and torque condition.

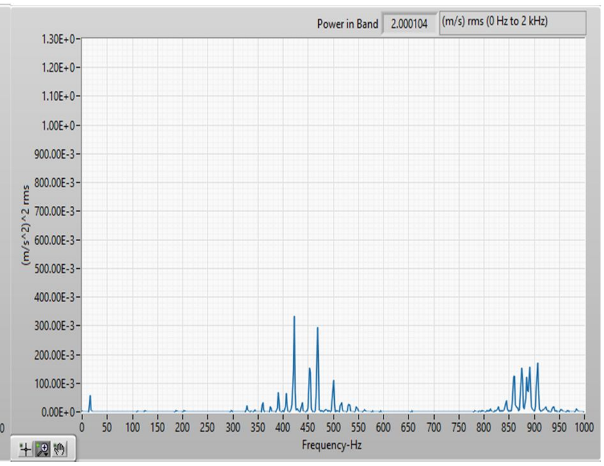
Comparison of RMS level for different operating condition of healthy and faulty gears is shown in fig 5. There is considerable variation in RMS level among healthy and faulty gears. But RMS level of the signals are found to increase significantly with respect to loads and speeds.

C. Frequency Domain Analysis

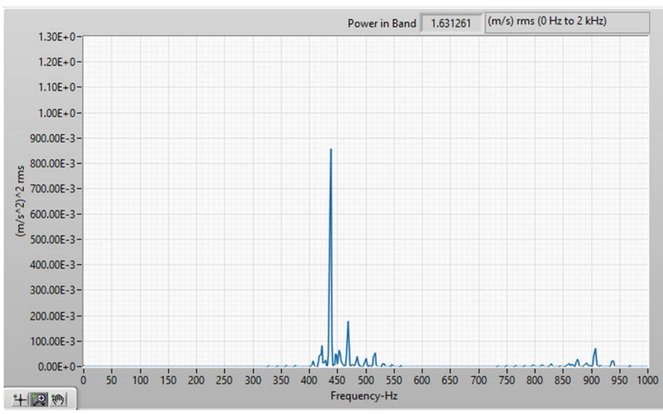
Frequency domain signals obtained after carrying out FFT of time domain signals are shown in fig-6 for gearbox with healthy and faulty gears. For the gear speed of 600rpm, gear shaft and pinion shaft frequencies are 10Hz and 16.071Hz respectively and the corresponding Gear Mesh Frequency (GMF) is 450Hz. Dominant peaks can be observed at GMF which are increasing with the number of cracked teeth. Crack at the gear tooth causes weakening of the gear at the root, resulting in larger deformation of the tooth while transmitting load. This results in change in the orientation of the cracked tooth and can cause increased tooth space locally. Because of the increased tooth space, there can be an impact force between the teeth, acting momentarily. The higher amplitude vibration signal at GMF in the case of gears with cracked teeth can be attributed to this impact force between gear teeth. Thus an increase in the amplitude of vibration signal at the GMF as indicated by the frequency spectrum can be attributed to initiation of crack at the root of the tooth.



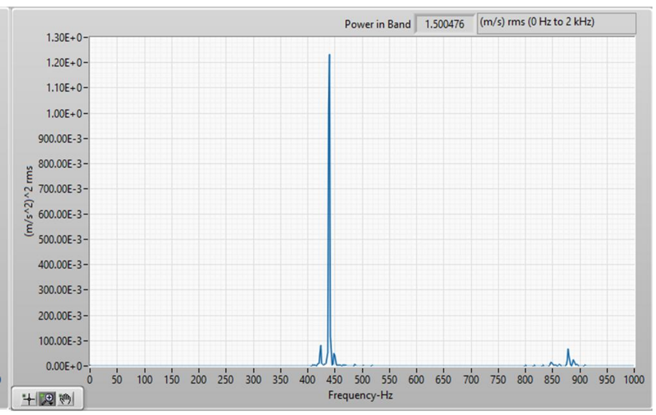
a) H



b) F1



c) F2

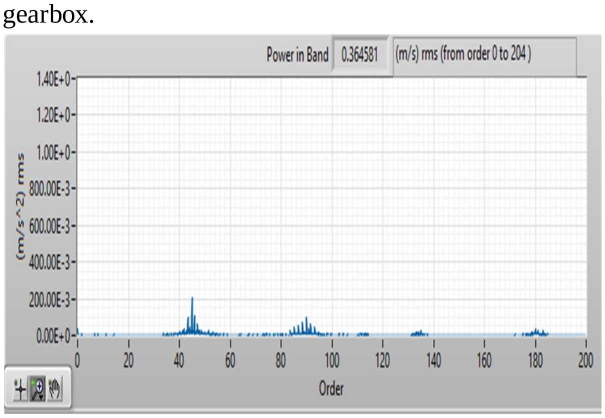


d) F3

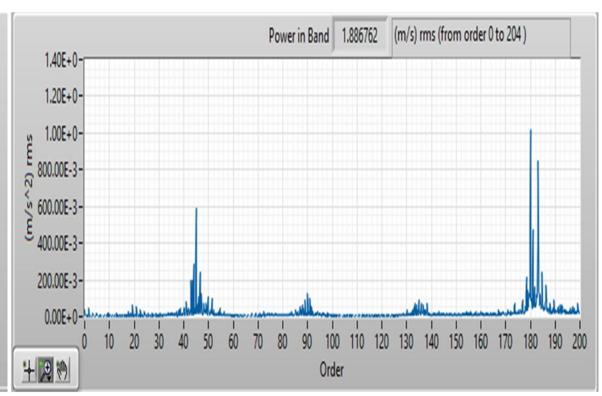
Figure 6: Spectra of healthy and faulty gearbox at the speed of 600rpm at Torque T2

D. Order Tracking Or Angular Domain Analysis

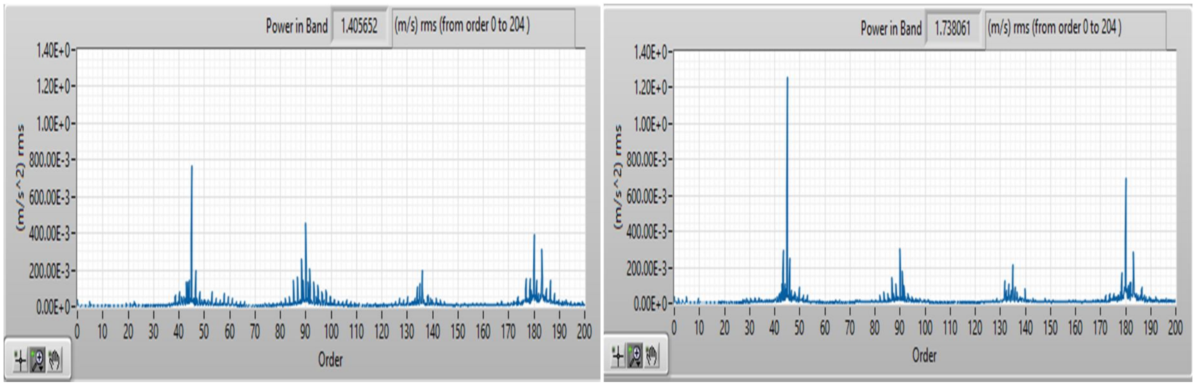
The order signal contains the vibration trend which is same as the spectrum signal shown earlier. The advantage of the order signal is that, there is no need to calculate the gear mesh frequency since the speed of the gear is expressed in terms of order and order one represent the speed of the gear. The fundamental speed of the gear is treated as the first order. The GMF has 45th order which depends on the number of teeth in the gear and its harmonics appeared at 90th, 135th, 180th orders etc. The difference between GMF and its sidebands can be easily identified in order analysis. Fig-8 shows the sidebands at the 45th order representing GMF for healthy and faulty gearbox.



a) H

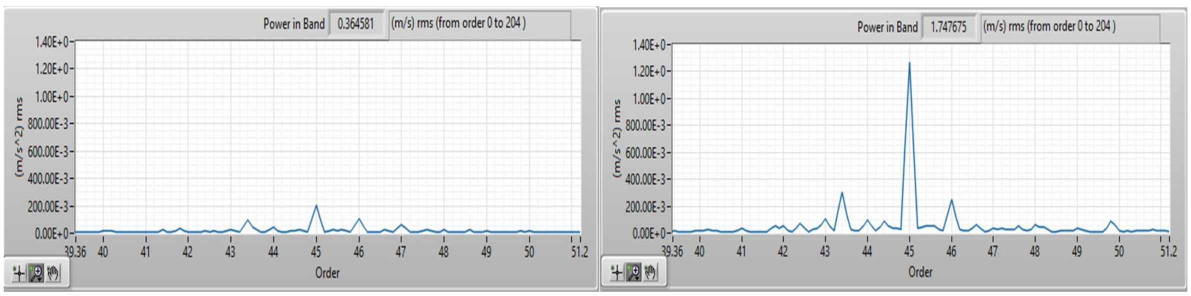


b) F1



c) F2 d) F3

Figure 7: Order signal of healthy and faulty gearbox at the speed of 600rpm at Torque T2



a) H b) F3

Figure 8: Zoomed signal around the 45th order for healthy and faulty gearbox

IV. CONCLUSION

The following conclusions are drawn from the vibration characteristics obtained from the present investigation.

A. Higher amplitude of vibration at gear mesh frequency are observed in case of gears having root cracks compared to those in healthy gears. Also higher order side bands are observed in case of gears with defects, at harmonics of gear shaft frequencies. These features observed from FFT signals are useful for identification of gear faults, when the system is in operation.

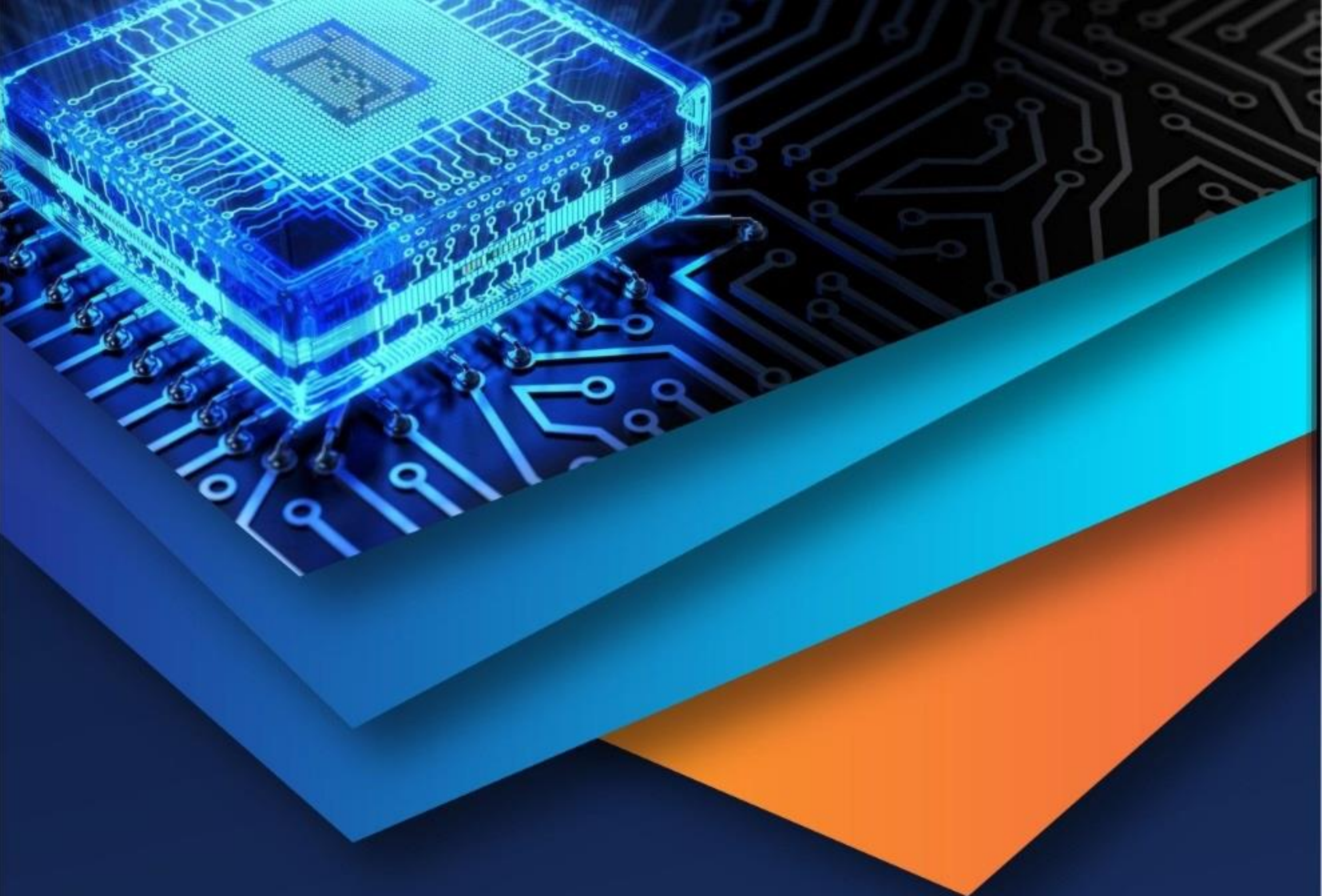
B. Signal obtained from order track analysis show similar trends, but they are more useful since the response in obtained in terms of order, which remains same irrespective of speed of the system.

V. ACKNOWLEDGEMENT

PG Center in Machine design, Department of mechanical engineering P.E.S.C.E, Mandya. I would like to thank my Guide Dr. Ajit Prasad S.L. and also our beloved HOD Dr.H.P Raju who gave me the opportunity to do the project on the topic, Vibration response of a gearbox having gear with teeth root cracks.

REFERENCES

[1] Song jingwei, Fault Detection and Diagnosis Based on Principal Component Analysis, China Plant Engineering, Vol.11, pp.37-41,2001.
[2] S. Rofe, “Signal processing methods for gearbox fault detection,” Defence Science and Technology Organization Technical Report, DSTO-TR-0476, Australia, (1997).
[3] A.Parey and N.Tandon. Dynamic modeling of spur gear pair Including a crack[J].ISCORMA-3,Cleveland,Ohio,2005, 19-23.
[4] Fakhfakh, T., Chaari, F., and Haddar, M. “Numerical and experimental analysis of a gear system with teeth defects”. Int. J Adv Manuf. Technol., page no. 542-550. 2005.
[5] Randall, R. B., A new Method of Modeling Gear Faults, ASME Journal of Mechanical Design, Vol. 104, April, 1982, pp. 259-267.
[6] mcfadden, P. D. “Detecing fatigue cracks in gears by amplitude and phase demodulation of the meshing vibration”. Journal of Vibration, Acoustics, Stress, and Reliability in Design, Vol.108, April 1986, pp, 165-170.
[7] Ju Ping-hua, Qin Shu-ren and qinyi, etc. “Research on earlier fault diagnosis of gear by method of multi-resolution empirical mode decomposition and frequency domain averaging”, Journal of Viberation and Shock Vol.28, Jun 2009, pp. 97-101.
[8] K.R.Fyfe, E.D.S.Munck. “Analysis of computed order tracking,” Mechanical Systems and Signal Processing, Vol.11, no.2, pp. 187- 205,1997.



10.22214/IJRASET

INDEX COPERNICUS
45.98

IMPACT FACTOR:
7.129

TOGETHER WE REACH THE GOAL
IMPACT FACTOR:
7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY