ISSN 2395-1621

Vibration Analysis of Diesel Engine with Three Speed, Four Speed Gearbox and Condition Monitoring

[#1]Mr. S.V.Dawange ,[#2] Prof.V.L.Kadlag

[1]satish.dawange@gmail.com

[2]vijay_kadlag@gmail.com

[#12]Sir Visvesvaraya Institute Of Technology, Nashik. India, Savitribai phule Pune University.

ABSTRACT

The energy produced by road roughness is dissipated through shock absorbers. Energy-harvesting shock absorber is capable for recovering that energy. It absorbs road vibrations and converts it into electrical energy. In this paper, design of regenerative suspension system is proposed, for improving the energy harvesting efficiency. Mechanical motion rectifier is used to convert oscillatory vibration into unidirectional rotation of generator. Static structural analysis is carried out to identify displacement and stresses by using software. In this project, a mechanical rack and pinion system is used to generate power through regenerative shock absorber. The validation is done by using experimental evaluation. The model achieved more than 50% efficiency at high frequency in oscillatory motion. This model can be used effectively in vehicles for power generation.

Keywords— **a DC motor, Energy harvesting shock absorber, Mechanical motion rectifier, Regenerative shock absorbers, Rack and pinion.**

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

Engine vibration measurement plays a very important role in automobile industry, the reason is, it indirectly related to two important parameters one is human comfort and other is failure of engine due to excessive of vibration. Engine consists of different components which have their own vibrations. The knowledge of numeric vibration data is very important to give importance to above two points. Some vehicle's engine comes with different kinds of gear boxes, meaning some automobile engine class (e.g. class A, Class B etc) are having three speed gear box and same automobile but different class have four speed or five speed gear box. So, if same engine is fitted with different gear box, how it will impact on the vibration of the engine is the area of interest. As per sensitive vibration measurement, it is accepted that vibrations are reduced with higher number of gear box that is three speed to four speed or four speed to five speed. Hence the aim of this is to measure and analyze what is the impact of converting the engine from three speed to four speed gear box and the effect of fault in gearbox on engine vibration by using FFT analyzer.

II. LITERATURE REVIEW

Lech Sitnik, Monika Magdziak–Toklowicz, Radoslaw Wróbel carried out tests on two spark-ignition engines: 1.4BZ 90CV CD and 1.4BZ120CV CD installed in new Fiat Bravo (model 198, version 54A) motor cars. The latter engine model (120CV) was equipped with a supercharging system. The research consisted in comparing engine vibrations measured in specific and representative points.. They found that the vibrations generated by the engine have a stationary character, the maximum vibration velocities are higher in case of the engine equipped with a supercharger[2]. L.Barelli,G.Bidini, C.Buratti, R.Mariani worked on a diagnosis methodology for internal combustion engines (I.C.E.) working conditions, by means of non-invasive measurements on the cylinder head, such as acoustic and vibration, related to the internal indicated mean effective pressure. He found that Monitoring working conditions and combustion quality in an internal combustion engine often requires intrusive techniques. [7]

Zunmin Genga, Jin Chena, J. Barry Hullb worked on to develop robust condition monitoring and prognosis technologies and systems for wind turbine gearboxes, a comprehensive review of the state-of-art of condition monitoring and fault diagnosis techniques has been carried out. He found that the recent advances in sensing and signal processing technologies have significantly improved the condition monitoring. [3]

Somashekar V., Dr.Satish,V, Jamuna AB., Ranjitha P**.** made research on condition monitoring technique of a small four strokes, single cylinder petrol engine using vibration signal analysis based on time domain, crank angle domain, and signal energy. [1]

G Diwakar, Dr. M R S Satyanarayana, P. Ravi Kumar. Performed experiment for the detection of the fault in Gearbox by the interpretation of vibration data and spectrums. The spectrums shows the fault in Gearbox when Gearbox is operated at different Gears on full loads[11]

III.OBJECTIVES OF RESEARCH

In all above research papers discussed, vibration of engines, gear box, generators are measured. Also the engine vibrations in above literatures have measured for different cylinder pressures, different fuel used and different injection systems. But, the direct correlation of DI engine vibration for three speed and four speed gear box is not available. Comparative analysis of vehicle vibration is done for two different kinds of engine which formulated the platform for comparative analysis of engine vibration which is coupled with different gear boxes.

The objective of this paper is to study the effect of change in gearbox on engine vibration and the effect of faulty gear box on engine vibration which can help in condition monitoring of gearbox by analyzing engine vibration.

IV. METHODOLOGY

Firstly, Vibration measurement of Mahindra CL 500 DI engine for three speed gear box with different gear ratios then analysis of data collected by accelerometer was done by using FFT (Fast Fourier Transform) Analyser. The gear box that was three speed, was altered by four speed gear box for same vehicle. Now, for the engine with four speed gearbox vibration spectrum was collected by using accelerometer for measuring vibration with same gears and speed and then analysis was done by FFT (Fast furrier transform) Analyser. The comparative assessment of vibration analysis was made for the engine with three speed and four speed gear box. Then on four speed gearbox teeth of second and third gear were removed by using gas cutter to create a fault and then effect of fault in gearbox on engine vibration was studied by comparing the vibration signature given by engine before cutting and after cutting the teeth on the gears in gearbox.

The test was taken by lifting the vehicle's rear wheel on screw jack and engine was allowed to run in neutral gear at idle condition, in first gear at 20 Km/hr, in second gear at 40 Km/hr and in third gear for 60 Km/hr. Similarly for four speed gear box which has taken the place of three speed gear box on the same engine above limiting value of the speed are kept constant. For the Mahindra CL 500 DI engine the vibration was measured first for three speed gear box and after that replacing three speed by four speed by using Accelerometer and FFT. The results on frequency domain graph obtained from the FFT software which installed in personal computer was compared for different gears that is Neutral, First, Second and Third gear for three speed and four speed gear box by doing the alteration of the gear box coupled to the same engine. Engine vibrations measured with four speed gearbox for different speeds and along different directions when gearbox was in good condition. To study the effect of fault in gearbox on engine vibration, fault was created by breaking teeth on second and third gear using gas cutter in four speed gearbox and again vibration of engine was measured for same speeds and directions. Comparison of vibration of engine before breaking and after breaking teeth was done. The result obtained by the FFT was of two types that is time domain and frequency domain. But, as the data available in research papers on engine vibration conclude that the dynamic behavior of engine vibration can be well understood by using frequency domain graphs rather than time domain. Hence, for doing the conclusion of this research work vibration of engine for two gear boxes for four different gears were done by using comparative graphs in frequency domain

.

V. EXPERIMENTAL SET-UP

The experimental set-up consists of DI Engine with three speed gearbox, four speed gear box, Accelerometer, FFT Analyser, Personal Computer, screw jacks arranged as shown in Fig.1.

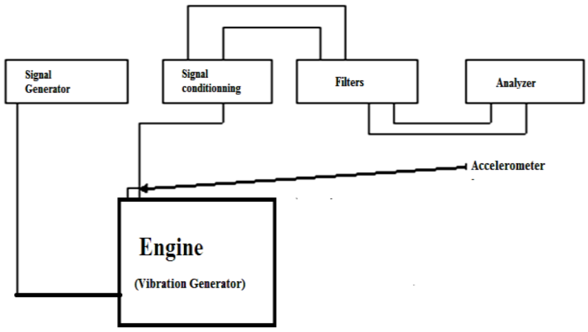


Fig. 1. Line Diagram of Experimental Setup.

Fig.2. Actual test setup.

The internal combustion (IC) engine is the concentrated mass in vehicle and if not properly designed it will cause vibrations and transfer to the supporting structures. Ride comfort, driving stability and drivability are important factors for the performance of a vehicle and are affected by the engine vibrations. Vibration behaviour of an IC engine depends on unbalanced reciprocating and rotating parts, cyclic variation in gas pressure, shaking forces due to the reciprocating parts and structural characteristics of the mounts. Engine produces the vibratory forces due to the unbalanced forces from the engine parts during the operation. The vibration caused by the engine at the supports is torsional vibration and the longitudinal vibration. The torsional vibration is caused at the crankshaft due to the fluctuating engine combustion pressures and engine loads. The longitudinal vibrations are caused at the block and the mounts by the reciprocating and rotating parts of the engine. Both the vibrations can be reduced by minimizing the unbalanced forces and by supporting the engine at proper mounts.

A) Engine: The diesel engine used for the experimentation has following specifications,

TABLE I.

DI Engine Specification:-	
Engine	Mahindra CL 500 DI (Direct injection)
Type	4 Stroke, 4 Cylinder, inline
Maximum Horse power	58 HP@3200 RPM
Maximum Torque	16.5 kgm@1500 RPM
Fuel Injection	Mechanical Fuel Injection System
Drive	Two wheel Drive (2WD)
Compression Ratio	18:1
Weight of the Engine	260 kg
Cooling System	Belt Driven Pump on cylinder head thermostat controlled
Transmission	Original Three speed and later on altered with four speed.

DIESEL ENGINE SPECIFICATION.

B) GEARBOX

A gearbox or transmission provides speed and torque conversions from a rotating power source i.e. engine to another device using Gear ratios. The most common use of gearbox is in automobiles where the transmission adapts the output of the internal combustion engine to the drive wheels. Such engines of automobile need to operate at a relatively high rotational speed, which is inappropriate for starting, stopping, and slower travel. The transmission reduces the higher engine speed to the slower wheel speed, which increases torque in the process. Thus gearbox coupled to engine plays vital role on the level of vibration produced. In this work we have measured vibration of engine when it was with three speed gearbox then by altering three speed gearbox with four speed gearbox and have done the comparison for minimum vibration of engine. Also this experimentation aims at the condition monitoring of gearbox through the measurement of engine vibration so we have created a fault in four speed gear box by braking teeth of second and third gear
in four speed gearbox and then vibration of engine have been checked by using FFT. Comparison has been done for vibration level of engine coupled to the gearbox without fault and with fault.

Gearboxes used for the experimentation were three speed and four speed with manual transmission as shown in Fig.

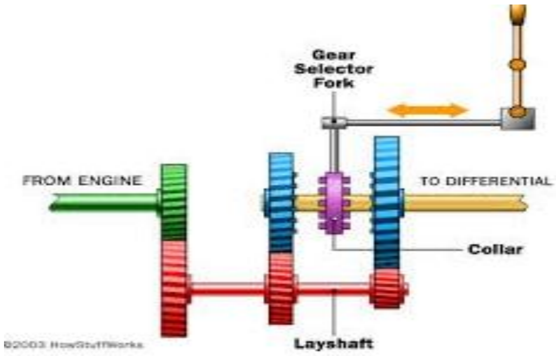


Fig.3. Three speed manual transmission gearbox

Fig.4. Three speed gearbox used in experiment.

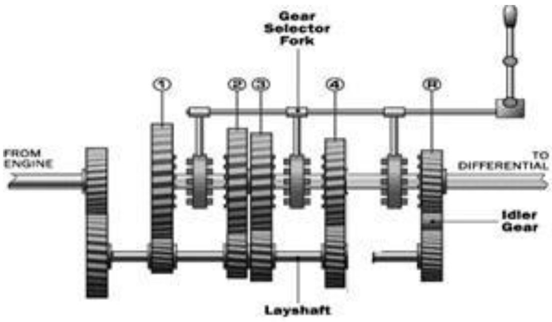


Fig.5. Four speed manual transmission gearbox.

Fig.6. Four speed gearbox used in experimentation

TABLE.II.

GEAR RATIOS OF THE GEARBOXES.

Gear Ratio	First	Second	Third	Forth	Reverse
3 speed gearbox	2.85:1	1.68:1	1:1	-	3.98:1
4 speed gearbox	3.98:1	2.368:1	1.437:1	1:1	5.3:1

C) FAST FOURIER TRANSFORM (FFT):

Vibration analysis is normally applied by using transducers to measure acceleration, velocity or displacement. The choice largely depends on the frequencies being analyzed acceleration covers region from 0 up to and beyond 20kHz.velocity covers frequencies typically from 2Hz to 2 kHz. Displacement a measure of absolute position covers frequencies from 0 up to 200Hz. The signals are a normally processed and stored using spectrum analysis method which take incoming signal and breaks it into its individual frequencies by using Fourier analysis. It relies on the ability to link particular frequencies to particular components such as bearing or Gears.

The Fast Transform (FT) and its inverse are defined as Follows,

$$F(\omega) = \int_{-\infty}^{\infty} f(t) e^{-i\omega t} dt \text{.................}(1)$$

$$f(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} F(\omega) e^{-i\omega t} d\omega \text{............}(2)$$

Where $f(t)$ is a given signal in the time domain and $F(\omega)$ is the FT of the $f(t)$ in the frequency domain. The FFT is a perfect tool for finding natural frequencies of structures but it cannot show the time information when a particular frequency component occurs. A vibration or a system response can be represented by displacement, velocity and acceleration amplitudes in both time and frequency domains (Figure). Time domain consists of amplitude that varies with time. This is commonly referred to as filter-out or overall reading. The measured vibrations are always in analog form (time domain), and need to be transformed to the frequency domain.[4]

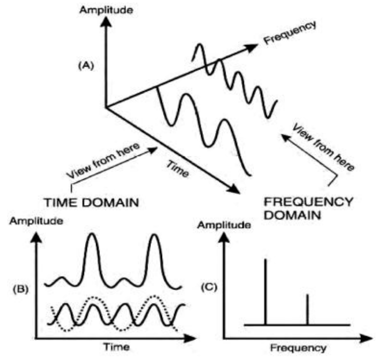


Fig.7.Principle of FFT.

The FFT analyser with accelerometer used in this experimentation is having following specification,

Make:-SKF Technology Co. Ltd.

Type:-SKF, Double channel

Fig.8.FFT analyzer.

Fig.9.Accelerometer.

VI EXPERIMENTATION WITH THREE SPEED GEAR BOX AND FOUR SPEED GEARBOX.

From above shown single channel FFT Analyzer was used and its data has been assessed by using personal computer. The software that was used for converting time domain signal to frequency domain signal was MCMe 2.OH. Initially engine was coupled with three speed gearbox and the rear wheels are jacked up with the help of screw jacks. For experimentation engine was run at different speed like in neutral gear at ideal condition, in first gear at 20 Km/hr, in second gear at 40Km/hr, in third gear at 60Km/hr respectively and the readings of an engine vibration were taken by mounting an accelerometer on cylinder head. The natures of spectrums obtained from FFT analyser were different for different speeds of an engine on the basis of frequency and amplitude.

After taking the results of engine vibration with three speed gear box, the engine was altered with four speed gear box and again by using accelerometer with FFT Analyser the readings were taken for same gear ratio that was for neutral gear, first gear, second gear and third gear by keeping same speed that is Ideal condition, 20 Km/hr, 40 Km/hr and 60 Km/hr respectively.

First Gear (3 speed GB) 20 Km/hr		
Sr No.	Frequency(Hz)	Amplitude (mm/s)
1	7.5	3.76
2	12.5	2.9
3	25	3.16
4	50	25.78
5	102.5	2.71
6	647.5	2.82
7	660	2.39
8	800	2.23
9	825	1.9

Fig.10. Mounting of accelerometer on engine.

Fig.11. Rear wheel jacked up.

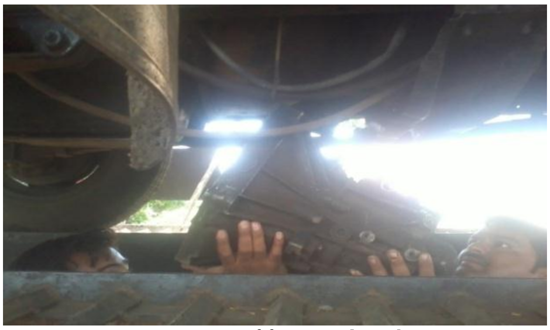


Fig.12. Fitting of four speed gearbox.

The nature of the FFT spectrums and tabulated results of frequency and amplitude for an engine coupled to three speed and four speed gearbox and running at 20Km/hr in first gear are shown in Fig

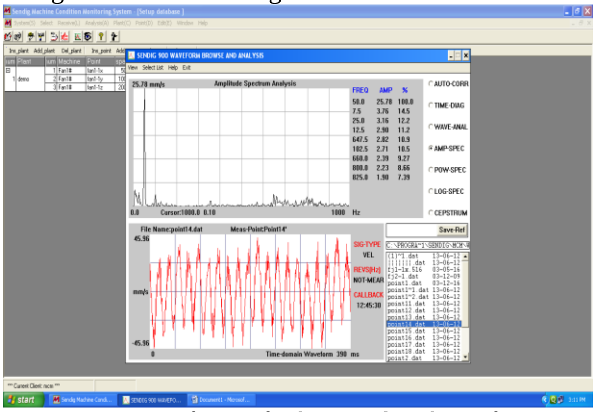
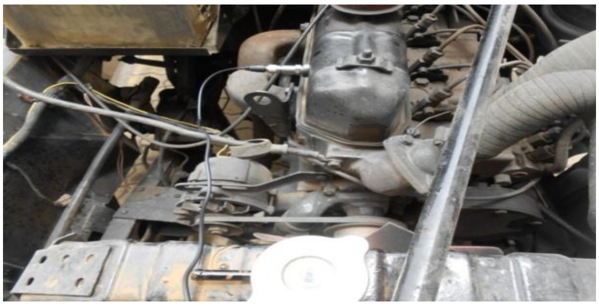


Fig.13. Spectrum of engine for three speed gearbox in first gear.

TABLE.III.

TABULATED VALUES OF ENGINE VIBRATION FROM FFT SPECTRUM.



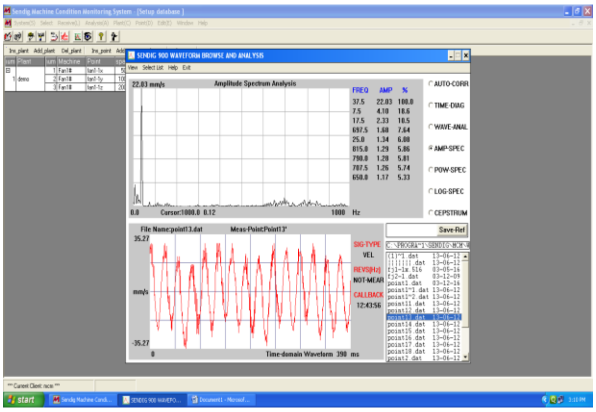


Fig.14. Spectrum of engine for four speed gearbox in first gear.

TABLE.IV.

TABULATED VALUES OF ENGINE VIBRATION FROM FFT SPECTRUM.

First Gear (4 speed GB) 20 Km/hr		
Sr No.	Frequency(Hz)	Amplitude (mm/s)
1	7.5	4.1
2	17.5	2.33
3	37.5	22.03
4	49	2.22
5	650	1.17
6	697.5	1.68
7	707.5	1.26
8	790	1.28
9	815	1.29

Similarly the numbers of readings were taken for engine vibration when engine was running at different speed in different gears by using FFT analyzer for three speed gearbox and then for four speed gearbox and comparison has been done.

VII. RESULT AND DISCUSSION

As elaborated earlier the aim of the work was to measure the vibration of 'Mahindra CL 500 DI engine' for three speed and four speed gear box by using instrumentation and then by comparing the analyzed data to plot different curves for different output.

The readings obtained are tabulated in excel sheet and comparative analysis was done with the graphs made from that sheet.

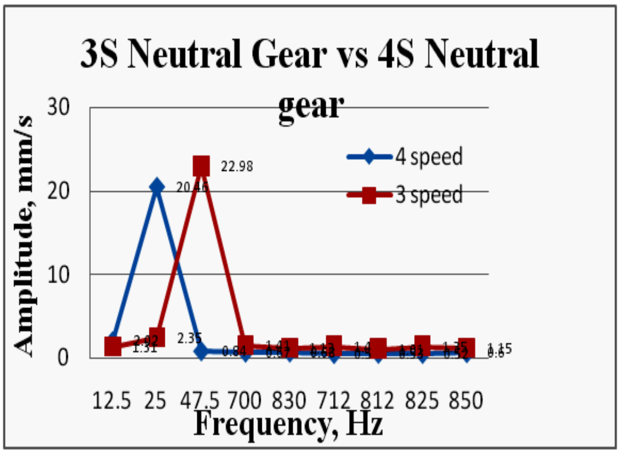


Fig.15.Graph of engine vibration for three speed and four speed gearbox in neutral gear.

From above frequency domain graph when the vehicle was in idle condition, the maximum amplitude of vibration for three speed gear box was 22.98 mm/s and for four speed gear box it was reduced to 20.46 mm/s.

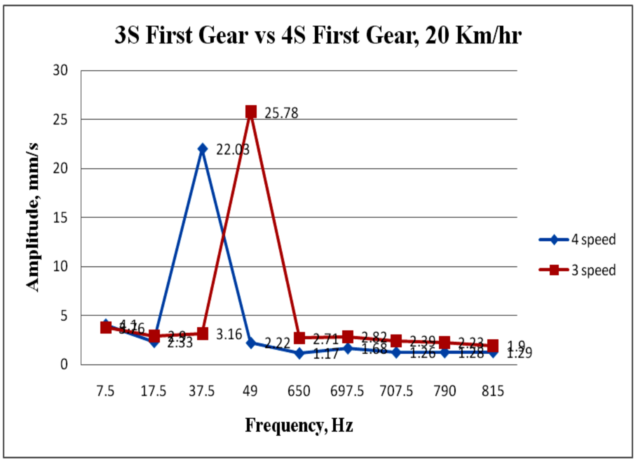


Fig.16.Graph of engine vibration for three speed and four speed gearbox in first gear at 20Km/hr.

From above frequency domain graph in fig when the vehicle was in first gear running at 20 km/hr, the maximum amplitude of vibration obtained for three speed gear box and four speed gear box was 22.03 mm/s and 25.78 mm/s respectively.

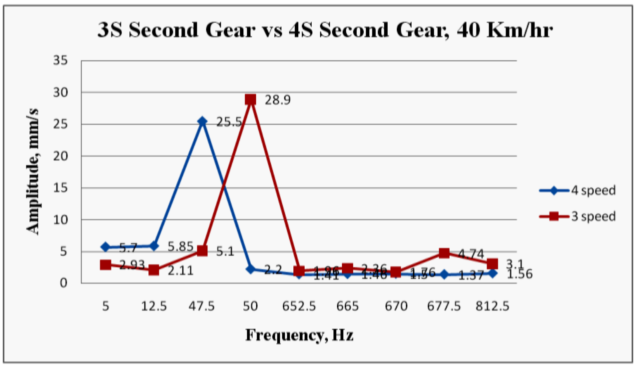


Fig.17.Graph of engine vibration for three speed and four speed gearbox in second gear at 40Km/hr.

From above frequency domain graph in fig 5.3 when the vehicle was in second gear running at 40 km/hr, the maximum amplitude of vibration obtained for three speed gear box and four speed gear box was 25.5 mm/s and 28.9 mm/s respectively.

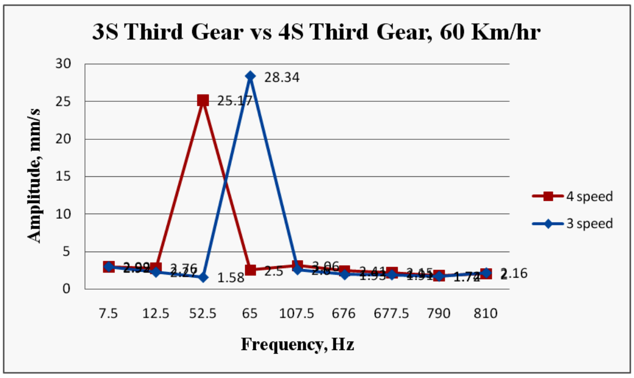


Fig.18.Graph of an engine vibration for three speed and four speed gearbox in third gear at 60Km/hr.

From above frequency domain graph in fig when the vehicle was in third gear running at 60 km/hr, the maximum amplitude of vibration obtained for three speed gear box and four speed gear box was 25.17 mm/s and 28.34 mm/s respectively.

The readings of maximum amplitude in mm/s for first gear, second gear and third gear for three speed and four speed are as follows,

It was observed that when engine was running at various speed (Idle condition, 20 km/hr, 40 km/hr and 60 km/hr) the amplitude of vibration decreases in each and every case for four speed gear box and its average percentage of variation for all three speed ratios are 12.52

TABLE.V.

TABULATED RESULT FOR % REDUCTION IN VIBRATION.

	Three Speed gearbox	Four speed gearbox	Percentage reduction in vibration.
First Gear	25.78	22.03	14.5
Second Gear	28.9	25.5	11.77
Third Gear	28.34	25.15	11.3

VIII. CONDITION MONITORING OF GEARBOX THROUGH VIBRATION ANALYSIS OF ENGINE.

The basic idea was that every moving component or physical process involved in the operation of an engine produces a vibration signal that is uniquely its own and to which we shall refer as a vibration signature. This central assumption motivates the measurement of vibration and its analysis as a means for condition monitoring. Condition of gearbox coupled to engine has adverse effect on engine vibration. In this work effort has been made to detect the fault in gear box through the vibration analysis of engine, which also helps to predict the effect of fault in gearbox on the level of vibration produced in engine. Such work has been carried out because as compared to gearbox engine is easily accessible for vibration measurement in any automobile.

For this experimentation we measured the vibration of engine in first, second, third& forth gear when it was coupled with four spped gearbox at particular speed by mounting accelerometer in horizontal, vertical and axial direction. Then we created a fault in gearbox by breaking the teeth of second and third gear in same gearbox by gas cutting. We measured the vibration of engine when it was coupled with faulty gearbox by running engine in all gears at same speed in three different directions by mounting accelerometer. Comparison of the vibration amplitude has been done from the values obtained from FFT spectrums for engine vibration in three directions before braking teeth and after breaking teeth.

Fig.19.Broken teeth on four speed gearbox.

The natures of the spectrums obtained before braking and after breaking teeth are shown in Fig.

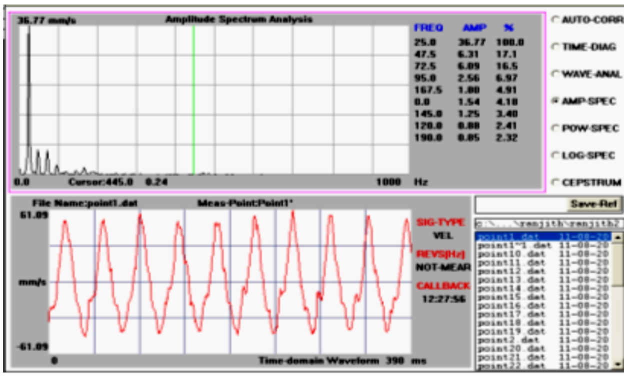


Fig.20.Engine vibration in second gear before breaking teeth.

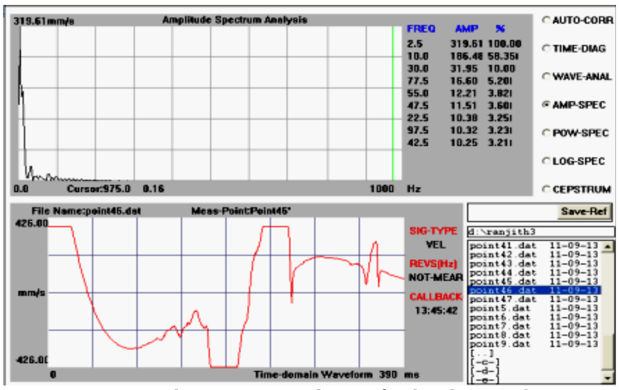


Fig.21.Engine vibration in second gear after breaking teeth.

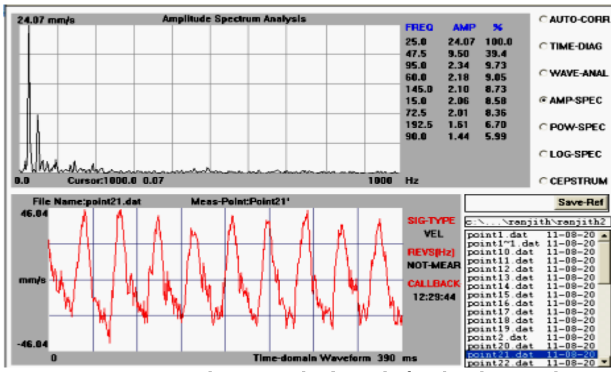


Fig.22.Engine vibration in third gear before breaking teeth.

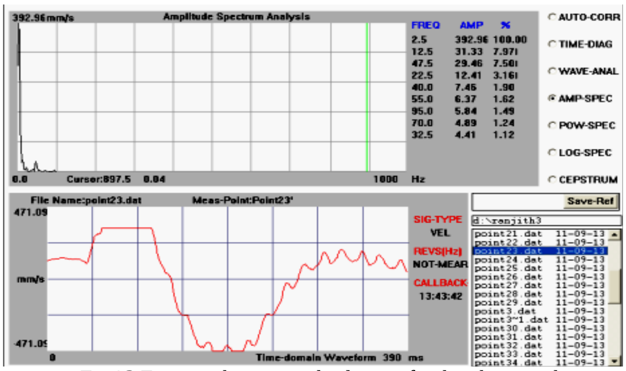


Fig.23.Engine vibration in third gear after breaking teeth.

Similarly numbers of reading have been taken for engine vibration and the values for the amplitude of vibration obtained from FFT spectrums before breaking teeth and after breaking teeth have been tabulated.

TABLE.VI.

MAXIMUM AMPLITUDE VALUES IN DIFFERENT DIRECTION IN SECOND GEAR

Maximum Engine vibration amplitude in third gear at	Before Breaking teeth	After Breaking teeth
Horizontal direction	24.07	392.16
Vertical direction	19.80	43.4
Axial direction	12.74	30.52

TABLE.VII.

MAXIMUM AMPLITUDE VALUES IN DIFFERENT DIRECTION IN THIRD GEAR

Maximum Engine vibration amplitude in Second gear at	Before Breaking teeth	After Breaking teeth
Horizontal direction	36.77	319.61
Vertical direction	20.53	43.62
Axial direction	15.41	27.53

Comparison of an engine vibration before breaking teeth and after breaking teeth has been done by plotting graphs in excels.

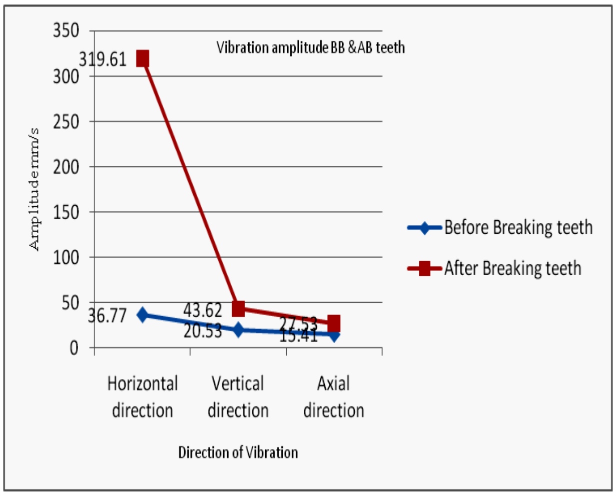


Fig.24.Graph of engine vibrations for second gear before and after breaking teeth.

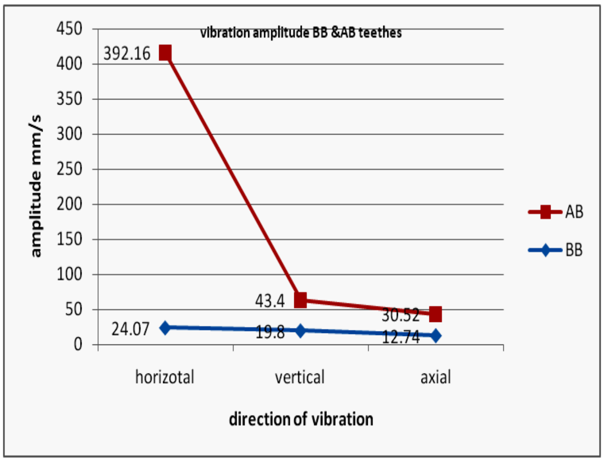


Fig.25.Graph of engine vibrations for third gear before and after breaking teeth.

IX. RESULT AND DISCUSSION OF CONDITION MONITORING

By observing the spectrums of engine before breaking teeth the peak amplitudes were at 1x. By observing the spectrums of engine after removing Gear teeth the peaks were present at sub harmonics and multiples of frequencies. The cause of presenting the sub-harmonics &multiples of frequencies was due to the presence of fault in the Gearbox.

From the graphs obtained in the comparative analysis of the vibration data it was clear that there was sudden increase in the vibration of engine in large extent after breaking the teeth of gear box. The vibrations increased from 5times to 8times after observing the spectrums. Such kind of analysis helps in detecting the fault in gearbox by measuring the vibration of an engine.

X.CONCLUSIONS

It is observed that vibrational analysis is better compared to other monitoring techniques. The vibration analysis of engine which is coupled with three speed and later on altered with four speed gear box is done by using accelerometer and FFT Analyzer for analyzing the data. This vibration of engine is measured in terms frequency domain graphs for different gear ratios and after comparing the results for three speed and four speed gear box we can conclude that if engine is replaced with higher number gear box the vibration of the engine is reduced.

This paper has investigated the detection of Gear fault using vibration monitoring of an engine. An experimental study has been conducted on engine with Gearbox, measured quantities such as frequency and amplitudes. The peaks are present at sub-harmonics and multiples of frequencies. The cause of presenting the sub harmonics &multiples of frequencies is due to the presence of fault in the Gearbox.

So it possible to condition monitor the gearbox by analyzing vibration of engine.

ACKNOWLEDGMENT

I take this immense pleasure in thanking Dr. S. N. Shelke, Head of the Department of SVIT Chincholi, Mechanical Engineering, and Prof. R. S. Shelke**,** for having permitted me to carry out this Work. I wish to express my deep sense of gratitude to my Guide, Prof. V. L. Kadlag for guidance and useful suggestions, which helped me in completing this Work in time.

REFERENCES

1) Somashekar V., Dr.Satish,V, Jamuna AB., Ranjitha P. “Vibration Signature Analysis of IC Engine” International Journal Of Research And Development, Vol 2, Issue 13,224-238.
2) Lech Sitnik, Monika Magdziak–Tokowicz, Radosw Wróbel “Comparative Analysis Of The Vibrations Of A Different Kind Of Engine Mounted In The Same New Motor Vehicles” Journal of KONES Powertrain and Transport, Vol. 18, No. 4 2011.
3) Zunmin Genga, Jin Chena, J. Barry Hullb “Analysis of engine vibration and design of an applicable diagnosing approach”, International Journal of Mechanical Sciences 45 (2003) 1391–1410.
4) Hamid Ghaderi , Peyman Kabiri “Automobile Independent Fault Detection based on Acoustic Emission Using FFT” SINCE2011 Singapore International NDT Conference & Exhibition , 3-4 November 2011.
5) Barshikar Raghavendra Rajendra, Santosh.V. Bhaskar “ Condition Monitoring of Gear Box by Using Motor Current Signature Analysis” International Journal of Scientific and Research Publications, Volume 3, Issue 8, August 2013 1 ISSN 2250-3153
6) P. Charlesa, JyotiK.Sinhaa, F.Gub, L.Lidstonea, A.D.Bal “Detecting the crankshaft torsional vibration of diesel engines for combustion related diagnosis”, Journal of Sound and Vibration 321 (2009) 1171–1185.
7) L. Barelli , G. Bidini, C.Burati, R.Marioni in their paper entitled ‘Diagnosis of internal combustion engine through vibration acoustic pressure non-instructive measurement’; Applied Engineering 29 (2009):1707-1713.
8) S.Vulli, J.F.Dunne, R.Potenza, D.richardson ‘Time frequency analysis of single point engine block vibration measurement for multiple excitation-event identification’, Journal of sound and vibration; Oct.2008:1129-1139.
9) M. Desbazeille, R.B.Randall , F.Guillet , M.ElBadaoui C.Hoisnard “Model-based diagnosis of large diesel engines based on angular speed variations of the crankshaft”, Mechanical Systems and Signal Processing 24 (2010).
10) Joe Deery, AIM and C, Newfoundland, New Jersey ‘The real history of real time spectrum Analyzer’;2006:54-58
11) G Diwakar, Dr. M R S Satyanarayana, P. Ravi Kumar “Detection of Gear fault using vibration analysis” International Journal of Emerging Technology and Advanced Engineering Volume 2, Issue 9, September 2012 123-137.

