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RESEARCH PAPER ON GEARBOX FAILURE ANALYSIS

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Abstract- *This paper presents an experimental investigation on gearbox failure of an automobile vehicle. Through the experiment it can identify the main causes of the issue and also the solution of the problem. There are various factors that affects and create a problem of gearbox failure. In this paper, discussion of some problems faced by the company along with their solution has been done.*

Keywords*-gearbox failure, automobile gearbox, vibration monitoring, failure pattern, frequency domain analysis, ball bearing*

I. INTRODUCTION

Any Vehicle needs high torque when climbing and while starting, even though they are performed at low speeds. On other hand, when vehicle runs at high speed they do not require high torque as they have a momentum of own. So the need of a device is occur, which can regulates the torque and its speed according to road condition or when the driver need. This device is known as gear box.

In the gear box, the counter shaft is mashed to the clutch with a use of a couple of gear. So the counter shaft is always in running condition. When the counter shaft is bring in contact with the main shaft by use of meshing gears, the main shaft start to rotate according to the gear ratio. When want to change the gear ratio, simply press the clutch pedal which disconnect the counter shaft with engine and change connect the main shaft with counter shaft by another gear ratio by use of gearshift lever. In an gear box, the gear teeth and other moving metal must not touch [1].

Problem define

One of the most irritating issues facing by the customer of company into vehicle is Differential failure. As it is occurring on road vehicle it is a serious issue. Sudden failure of gearbox can cause damage to vehicle as well as the humans also. As the company gets gearbox from the field it is not easy to find main reason behind gearbox failure as the gearbox is found in such condition from that it is not possible to identify component.

II. METHODOLOGY

As the gearbox failure occurs in field, it should be rectify. Failure pattern of gearbox should be found after that the vibration monitoring will done on some filed vehicles and cross check both the conclusions will be done.

A. Failure Pattern

For finding the failure pattern the 5 why analysis has to be done on gearbox. 5 Whys is an iterative interrogative technique used to explore the cause-and-effect relationships underlying a particular problem. The primary goal of the technique is to determine the root cause of a defect or problem by repeating the question "Why?" Each answer forms the basis of the next question. The "5" in the name derives from an anecdotal observation on the number of iterations needed to resolve the problem.

B. Vibration Monitoring

Vibration monitoring is a commonly used technique for condition based monitoring, but it is done with test rings or a lab condition, here the real road condition vibration monitoring will be done on vehicle.

As we are facing problems after the vehicle runs over an average of 7000 KMS. The test will be done on the vehicle which is already covered 7000 KMS. A Gem diesel vehicle is selected for a vibration monitoring. Also vibration analysis will be done on newly made Gem vehicle, to ensure the fault. Accelerometer (Piezoelectric) will be mounted on a gearbox. Vibration graph data will be generated from accelerometer. Time-domain and frequency-domain will be calculated from vibration data and fault diagnosis will be done for gearbox.

C. Time Domain Analysis

It is obtained from the Vibration signal generated from vibration monitoring. Calculations are mentioned here:
Peak value: It is the maximum value in the given signal X max).

Standard error: It measures the error in prediction of y for a value of x.

$$\text{Standard error}=\frac{S}{\sqrt{\text{n}}}$$

where n is the sample size and S is the sample standard deviation

$$S = \sqrt{\frac{1}{n}\sum(x-\bar{x})^2}$$

Where x is the sample datum, $\bar{x}$ is the mean of sample data

Root mean square (rms) it is the square root of the mean of square of the sample data.

$$rms = \sum \frac{x^2}{n}$$

Kurtosis: It measures the flatness or peak-ness of a sample data.

$$kurtosis = \frac{n(n+1)}{(n-1)(n-2)(n-3)}\sum\left(\frac{x-\bar{x}}{s}\right)) - \frac{3(n-1)^2}{(n-2)(n-3)}$$

krms: It is a factor derived to show the change in rms for large values of kurtosis.

$$krms = rms * kurtosis$$

Variance: It is the square of sample deviation used to measure the spread of the
sample data.

$$variance = S^2$$

Crest factor: It is the ratio of peak value to the rms value.

$$crest\ factor = \frac{peak\ value}{rms}$$

Skewness: It is the measure of symmetry of a distribution.

$$\sum\frac{(x-x^3)}{n.S^3}$$

D. Frequency Domain Analysis

Fast Fourier Transform will be performed on the time waveform for obtaining frequency domain. From the frequency domain, the frequency of each failure conditions will be identified and diagnosis can be done on observing frequency domain analysis.

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III RESULTS AND DISCUSSION

A. Failure Pattern

From the gearbox problems like noise, hard gear shifting or main housing broken are coming.

Figure 1. Main housing broken

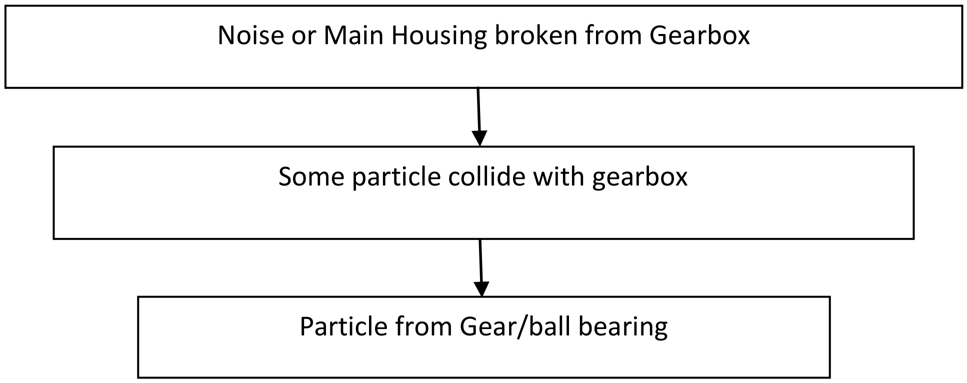
Also some other components such as ball bearing, gears are found broken or damaged.

Figure 2. Ball bearing broken

Figure 3. Gear damage

From visible inspection we can see that Main housing is broken due to the some heavy particle collide to it, the metal parts of ball bearing and gears found in the housing , the metal particle should be responsible for the Main housing broken.

Metal particles comes from the any part failure of gearbox, so the part failure of any component inside gearbox is responsible for gearbox failure. It may be from gear or ball bearing. Rubbing and shining mark found on the Ball bearing, we but it has to be verify with the vibration analysis. Flow chart for methodology is shown here.



B. Vibration Monitoring

A Gem dz vehicle, which has a 4 speed synchromesh gearbox, has been chosen. The Gear ratios are shown in Table 1

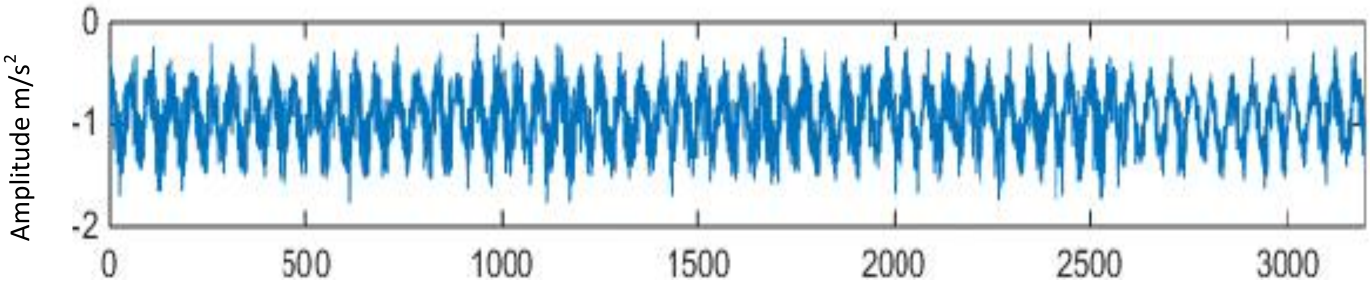
Table 1. Gear ratios

GEARS	GEAR RATIO
FIRST	2.87:1
SECOND	4.60:1
THIRD	2.07:1
FOURTH	1.67:1
REVERSE	3.62:1

Now to Accelerometer is mounted on the gearbox and the vibration signals from gearbox will be gendered in the computer attached to accelerometer with USB cable. The vibration graph will generated in the Lab view software .here every component failure has its own frequency but it has to be abstract from the graph by suitable method.

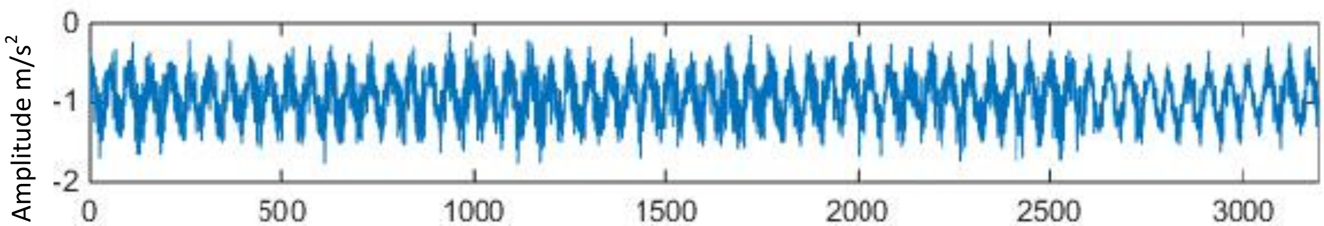
Here Time domain and Frequency domain analysis can be done, but due to limitations of Time domain analysis, Frequency analysis will done.

As vehicle is in on road conditions have to face much worst condition, the test will also performed in such conditions. The vehicle will run on the full throttle speed on a road with many obstacles, to have the real road conditions and speed.



Graph 1. New vehicle Vibration signals acquired for 4th gear 50 km/hr

The Graph 1 shows vibration signals of a new vehicle at 50 km/hr at 4thgear with the shaft speed of 11200 RPM.

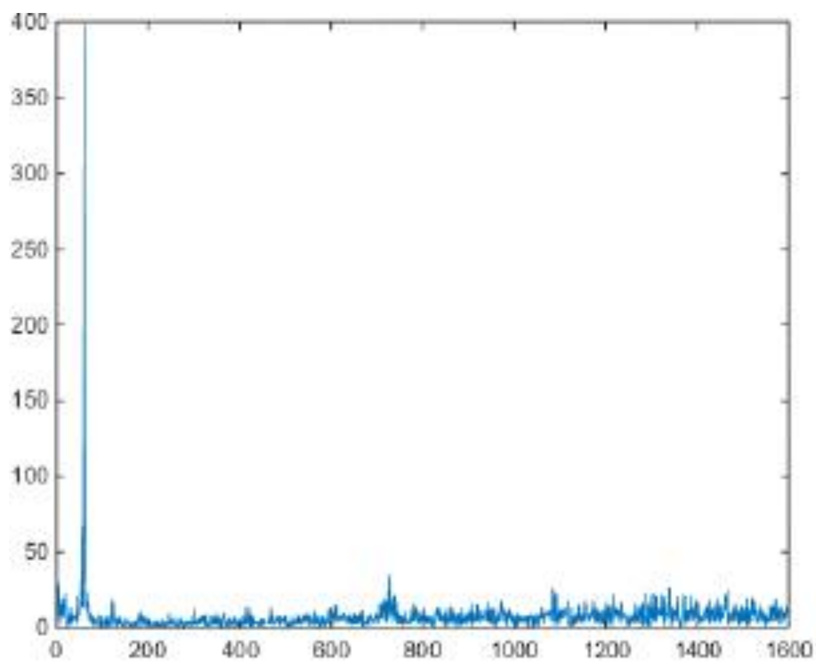


Graph 2. For old vehicle Vibration signals acquired for 4th gear 50 km/hr

Graph 2 shows old vehicle running at speed of 50 km/hr at 4th gear with the shaft speed of 11200 RPM.
For getting the proper data and for better analysis the Fast Frequency Transform has to be done on Vibration signals to get Frequency signals

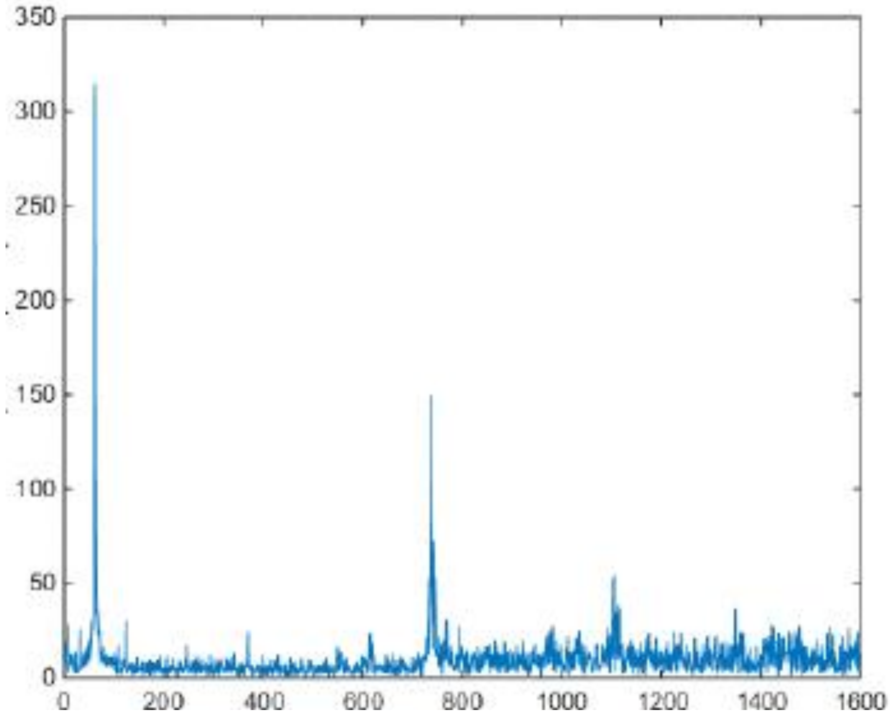
C. Frequency Domain Analysis

By Fast Frequency Transform we get graph of a new vehicle running at speed of 50 km/hr at 4th gear. Here we cannot see any abnormal rise in frequency graph. Thus it can be say that the new vehicle does not have any problem in gearbox, but this Graph has to be compare with the old vehicle graph to get better idea.



Graph 1. New vehicle frequency domain analysis

By Fast Frequency Transformation on vibration signals Graph 4 of a old vehicle running at speed of 50 km/hr at 4th gear generated.



Graph 2. Old vehicle frequency domain analysis

By comparing Graph 3 and Graph 4 we can see that there is abnormal rise in a Frequency at 750 Hz.
For knowing the frequency of failure calculation has be done.
As per 5 why analysis the bearing and tooth failure resemble major defect the calculation will be done for them first. If no frequency match then other failure frequency will be calculated [2].
For Ball bearing Failure frequency

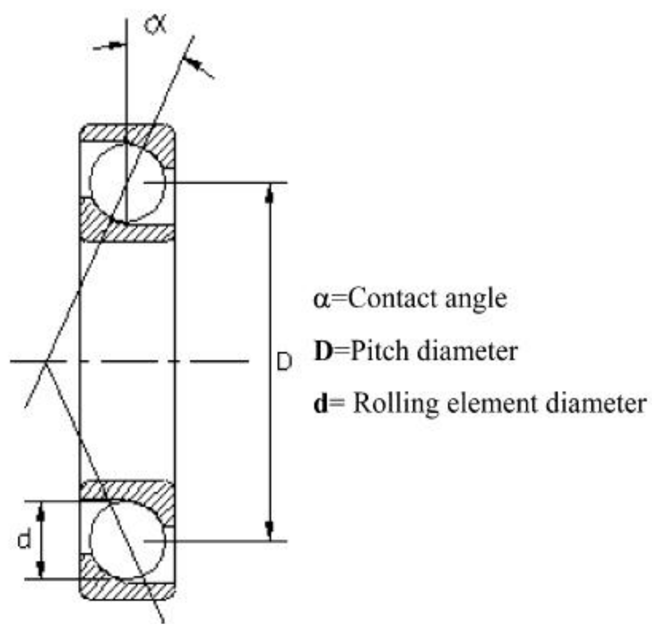


Figure 4. Bearing geometry

$w_c = \frac{n}{2}\left[1 - \frac{d}{D}\cos(\alpha)\right]$

$W_b = \frac{n}{2}\left(\frac{d}{D}\right)\left[1 - \left(\frac{d}{D}\right)^2 cos^2\,\alpha\right]$

w_{bp}= N (w_c)

w_{bpI}= N ($n - w_c$)

Where n is shaft speed per second

d is diameter of ball in mm

D is diameter of bearing in mm

α is a contact angle (It is taken as 0)

N is number of balls in bearing

w_c is fundamental train frequency

w_b is ball spin frequency

w_{bp} is outer race frequency

w_{bpi} is inner race frequency

For our case

N = 9 d = 5.5 mm

D =52 mm

n= 11200 RPM

=186.6 Hz

$w_c = \frac{186.6}{2}\left[1 - \frac{5.5}{52}\cos(0)\right]$ = 93.3 (0.7885)

= 83.42 Hz

$W_b = \frac{186.6}{2}\left(\frac{5.5}{52}\right)\left[1 - \left(\frac{5.5}{52}\right)^2 cos^2\,0\right]$ = 93.3 (0.1057)(0.7885)

= 7.77 Hz

w_{bp}= 9 (83.42)

= 750.940 Hz

w_{bpI}= 9 (186.6 − 83.42) = 9 (103.18)

=928.62 Hz

As we can see that w_{bp} is 750 Hz, which shows that the outer race off ball bearing has some problem.

The ball bearing is manufactured by National Bearing Company (NBC).

Figure 5. NBC ball bearing

As the outer Here Ball Baring Code is 6205C3.which means

6	Deep ball bearing
2	Series 2
05	Bore diameter 5*5=25 mm
C3	Tolerance Limits

As the outer race of ball bearing is showing problem, there must be problems with tolerance limits of ball bearing and Housing.
Tolerance limits as per NBC are [3], [4]:

Use	Application	Fit Type	Cup O.D. D*	Housing Bore D*	Fit	Cup O.D. D*	Housing Bore D*	Fit	Cup O.D. D*	Housing Bore D*	Fit
			Less 3" O.D.			3" to 5"O.D.			Above 5" O.D.		
Auto-motive	Front wheels, full floating rear wheels pinion, differntial	Non-Adjustable cups	+0.0010 -0.0000	-0.0015 -0.0005	0.0025T 0.0005T	+0.0010 -0.0000	-0.0020 -0.0010	0.0030T 0.0010T	+0.0010 -0.0000	-0.0030 -0.0010	0.0040T 0.0010T
	Differential	Non-Adjustable cups	+0.0010 -0.0000	+0.0010 +0.0020	0.0000L 0.0020L	+0.0010 -0.0000	+0.0010 +0.0020	0.0000L 0.0020L	+0.0010 -0.0000	-0.0000 +0.0020	0.0010T 0.0020L
	Rear wheels, trans-mission, cross shaft & other application	Adjustable cups	+0.0010 -0.0000	-0.0000 +0.0010	0.0010T 0.0010L	-0.0010 -0.0000	+0.0000 +0.0010	0.0010T 0.0010L	-0.0010 -0.0000	-0.0000 +0.0020	0.0010T -0.0020L

*D - Normal cup O.D., L - Loose, T - Tight

Figure 6. Tolerance for NBC bearing [3], [4]

For our case bearing the Housing Bore tolerance is +0.0030 to -0.0010.
In CMM it is found that the tolerance limits is between the +0.003 to -0.022, which is not in the limits. Here more clearance is provided.

Figure 7. Measurements on CMM

Bearing OD is higher than the OD of housing, bearing is press fitted here. Bearing clearance will decreases as temperature increases inside gearbox. But already more tolerance is provided which means that at higher the clearance will be more compare to desired value. So the bearing is loosely fitted inside housing, which will rotate at higher RPM, and also failure of other components. The new Tolerance Limit for Housing is +0.0030 to -0.0010.

Figure 8. Housing with new tolerance

IV. CONCLUSION

This research paper concludes the reason behind gearbox failure and its solution..
- ☐ Gearbox failure is due to the ball bearing failure.
- ☐ There is a Ball bearing failure due to the more tolerances provide in housing
- ☐ New Housing with suitable tolerances has been suggested.

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