ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 1, Issue 5, November 2012

Failure analysis of compressor & camshaft gear– An experimental approach

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Abstract- This paper reports the result of an investigation of premature failure of compressor gear, camshaft gear (ie; spur gear). In this paper three 1616 CR BS III Engine investigated for subjected to matter in different types of H series vehicle. A standard investigation procedure was employed in this analysis under various conditions. It was found by analyzing various observations the gear shaft was bending and teeth failure on endurance on engine occurred under these testing ,in this paper overload test engine (on test bed) and different types of vehicle used for testing by running them at different-different speed and distance to calculate accurate reason of gear failure.

Keywords: compressor gear, teeth failure, endurance, Failedgear

1. INTRODUCTION

Gear is used almost all engineering purpose for power transmission for easily transmission & simplification in operation without any complex handling its suits to all engineering operation [1] Here we took a gear of air compressor and camshaft for testing of three 1616 CR BS III Engine for various investigation. .in this paper we analyses of failure of gear of air compressor and camshaft gear and tested it by different testing procedure and run this engine in different types of H series vehicle at different –different speed.

First we consider a table of gear module and design the gear at the given specification. After testing, its found shaft was bent and gear has come out of engagement from camshaft gear. The teeth failure on endurance engine after running of engine at certain period also occurred. With this testing procedure we examined the main causes of failure of gear. We can eliminate these reasons to some extent by applying suitable methodology in its design, operational and manufacturing procedure. With the help of this testing result and observations we find out the main causes of gears failure. The table below gives specification of 1616H BS-III

Specification of 1616H BS-III

1616H - BS III

Features:	Used in General Goods, Petroleum and Water tanker, Courier, Logistics, White Goods etc
Engine:	H Series WO6DTI 3N Turbo Charged Inter cooled: Bharat Stage III
Max Power:	167 PS (123 KW) @ 2400 rpm
Max Torque:	55 kgm @ 1500 rpm
Clutch:	Single plates dry type 356mm dia Ceramic
Gear box:	5 speed Synchromesh
Rear axle:	Single speed hypoid
Suspension:	Semi elliptic leaf springs in front and rear
Steering:	Integral power steering
Tyres:	10.00 x 20 - 16 PR
Brakes:	Dual line Full air
Cabin/ FES:	All steel G45 Mark III
Max Grade ability:	27.00%
Max Speed:	74.5 Kmph
GVW:	16200 kgs

2. REVIEW ON GEAR FAILURE

(i) Xiao-Leixu,Zhi-Weiyu,Yuming Gao,Tie-non Wong has investigated "the crack failure of gear used in generating electricity equipment wind paper " in this work A failure investigation had been conducted on the two failed helical gear which were used in generating electricity by wind power fractrography investigation on the cracked teeth indicated that the crack origins are about 3mm from the groove and exhibits point like features. The cracking nature of two gears attributes to the once instantaneous cracking metallurgical analysis indicates that cracking of teeth occurred during the carburization quenching process. [2]

And the result of this study shows that the presence of the number of inclusion cluster consisting of Al_2O_2 Complex inclusion in the crack origins zones is mainly responsible for cracking of the gears.

(ii) Abhay K. Jha,V. Diwakar presented a "metallurgical analysis of failed gear" in this paper Recently fracture of gear teeth occurred when a gear was in use. The fractured gear teeth were subjected to detailed analysis using std. metallurgical techniques. The result revealed that corrosive wear at the root fillet caused pitting intense localized plastic strain and fold leading to crack formation

And the result of this analysis work is Advancement of the crack took place under the successive stress repetitions to which the gear was subjected causing the tooth to fail by fatigue. [3]

(iii) P.J.L. FERNANDES investigated "tooth bending fatigue failure in gears" in his investigation Tooth bending fatigue failure one of most common fatigue failure. In gears it result in progressive damage to gar teeth and ultimately leads to complete failure of gear the characteristics of failure mode are discussed in detail and a number of actual case studies are presented which show the occurrence of this failure mode in practice [4]

And the final conclusion of his study shows that from the preceding section therefore the characteristics of tooth bending fatigue failure can be summarized follow.

- Fatigue crack originate at root radii of active side of tooth.
- Due to load shedding that occurs at the crack tooth is deflected tooth bending fatigue usually leads to failure

(iv) S. Cicero,R. Ciceror, Localleg, Diazd,Ferrono done his work on "failure analysis of lift gear shaft" in this paper analysis the failure of lift gear shaft which happened when the lift was carrying three people fortunately the safety system worked and there were no serious injury but when an investigation into the causes of that accident the analysis was performed using the FITNET FFS fatigue module and improper working conditions have been identified the major causes of accident.

And the final conclusion of this of this work The failure of lift shaft gear has been analyzed firstly a fatigue process has been identified as the original causes of the failure then a fatigue analysis has been performed following the FITNET FFS procedure it has been concluded that no fatigue problem should have occurred in failure section and also that this section should not have been the most stressed one the hypothesis that explain the fatigue process and fact that the failure section was most stressed is an improper operation of gear unit with unsecured bolts in the main support of the shaft that increases drastically the stress in critical section [5]

(v) Ales Belsak,Joze Flasker has completed his analysis work on "Wavelet analysis for gear crack identification " Fault analysis presented in this article are based on gear units with real damage s or fault produced on the basis of real operating conditions a test plan has been used a possible damage can be identified by monitoring vibrations .the influences of the crack in a single stage gear unit on produced vibrations are presented. A fatigue crack in the tooth root causes significant changes in tooth stiffness where as in relation to other faults changes of other dynamic parameters are mare exposed different method are used to analyses signals acquired by experiments signal analysis has been carried out in relation to a non stationary signal using the family of time frequency analysis tools such as wavelet Analysis typical spectrogram and scalogram patterns resulting from reactions to faults or damage indicate the presence of a damages in a reduce way.

And the result of this study Vibrations analysis aimed at detecting faults in industrial gear units at presented. This method described can improved the safety of the operations and the reliability of monitoring operational capabilities on the basis of wavelet transform it is possible to in very short time identify changes and to determine the presence of damage at the level of an individual tooth. [6]

3. EXPERIMENT WORK

3.1 Experiment Data Collection

The detail of compressor, camshaft and FIP gear parameters shown in table below with modified module.

Table .1 Gear Parameter Table with Modified Module

Gear	Parameter	697 BS-III Previous (2 module)	697 BS-III modified (2.05 module)
Camshaft	No of Teeth	82	78
	Normal Module	2	2.05
	PCD	178.909	181.7771
	Normal pressure angle	20	20
	Helix angle at PCD	23°33'22"	28°24'
	Root circle diameter	174.2	174.45
	Tip circle diameter	183.709	187
FIP	No of Teeth	82	77
	Normal Module	2	2.05
	PCD	178.909	179.4467
	Normal pressure angle	20	20
	Helix angle at PCD	23°33'22"	28°24'
	Root circle diameter	174.2	172.12
	Tip circle diameter	183.709	184.67
Air compressor	No of Teeth	38	36
	Normal Module	2	2.05
	PCD	82.909	83.8971
	Normal pressure angle	20	20
	Helix angle at PCD	23°33'22"	28°24'
	Root circle diameter	78.26	74.47
	Tip circle diameter	87.88	87.31

Three 1616 CR BS III engine investigated for the subject matter:

1. **Overload test engine (on test bed):**

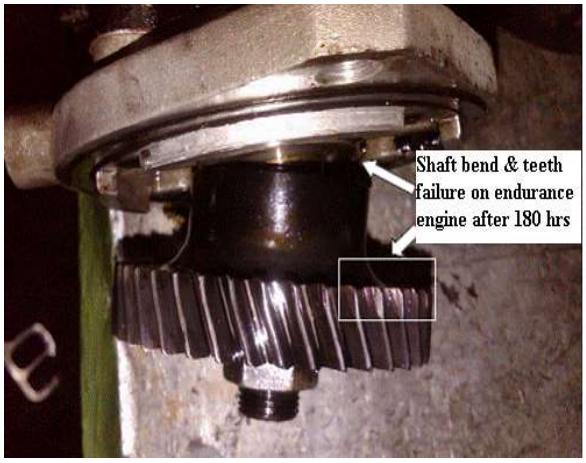

Fig1 Teeth Failure of Gear

Observations are as follows:

- The shaft of the air compressor gear is bent and the gear has come out of the engagement from camshaft gear
- The air compressor shaft can be rotated only for part of the revolution; subsequent to this it gets locked. When the compressor head was opened it was observed that inlet valve head was broken and got entrapped between the piston and the cylinder head, preventing the rotation of the compressor camshaft.
- The air compressor gear can be rotated on the compressor shaft. Some material adhesion is observed on the cone ID of the gear.

Wabco have indicated the design of gear and its fastening is investigated in view of the rotation possibility. As seen from snapshot below, the distance between the gear clamping face and end of cone in 2 mm, this will always ensure that the gear is rigidly clamped on the cone surface.

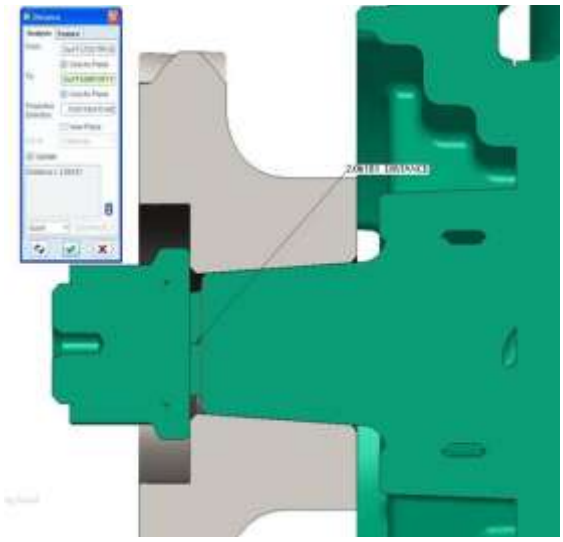

Fig.2 shows snapshot image of clamping arrangement

Going by the preliminary investigation by the supplier the possibility of nut loose cannot be overruled as we had already taken up with JSR regarding such cases observed earlier on two occasions'. While as mentioned in the investigation this doesn't answer for the inlet valve breakage issue (which could also be the root cause of failure: valve head breakage leading to physical locking of the piston motion, creating a shock load and hence bending of the compressor shaft)

Fig.3 teeth failure camshaft gear after 16k km running.

2. **Vehicle H 411** Vehicle runs for 16k kms. Observations are as follows

a. The compressor gear has got inner corner material dislodged on two of its teethes. This is typical case of edge loading of the gears which could be due to issue of parallelism of the two shafts (air compressor gear drive shaft and the camshaft drive shaft).

b. Camshaft gear
i. There is material erosion on the camshaft teeth on non driving flank wrt FIP / compressor gear. The back face of the camshaft gear shows rubbing marks on the face. And material of ~1.5 mm depth is cut out on the Timing gear housing corresponding to this face.

Typically in assembled condition there is a gap of around 5 mm between the camshaft gear face and the TGH (as shown in snap below). This type of rubbing could be explained if the spacer / thrust washer is not assembled during the engine assembly and the camshaft gear shifts back leading to rubbing against the TGH.

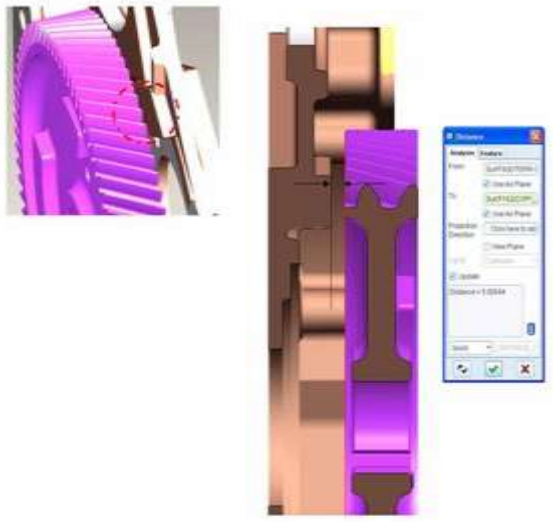

Fig.4 snapshot image of clamping arrangement of cam gear

ii. While during investigation of this case we found that camshaft gear was 5 mm away from the TGH face as required in design, but the above rubbing marks and the material cut in TGH indicate that at some earlier stage the possibility identified in point 1 must have occurred.

The damage observed in points a & b above will be due to the TGH material cut out getting entrapped between the gear teeth leading to damage / parallelism issues.

3. Vehicle H 405: Key observations are as follows

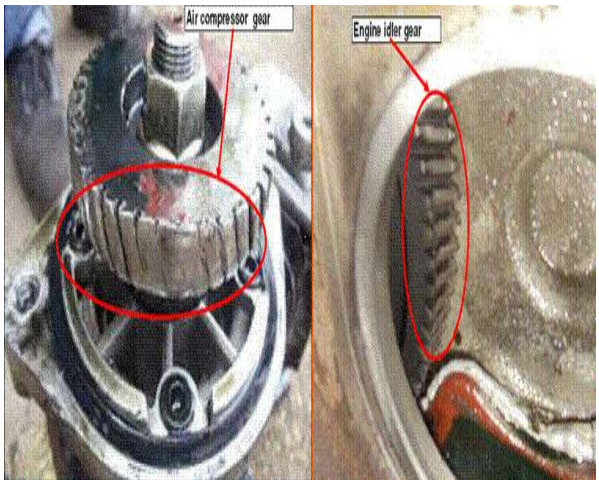

Fig.5 air compressor teeth failure

a. Vehicles run for 20K kms.
b. Camshaft gear: The gear teeth are cut off unevenly (radially) over circumference.
c. Compressor gear: The teeth are burnished. The burnishing phenomenon is observed to be eccentric to centre (some teeth are burnished close to root while the others are close to the gear tip)
d. One of the compressor mounting bolts was found in loose condition.

RESULTS

This type of failure occurred due to:
 there is some foreign particle getting entrapped in camshaft and compressor gear, leading to the teeth breakage of the camshaft gear and the consequential failure on compressor gear there on.

 there is some locking / shock load coming from the driven gear (air compressor gear). The air compressor was investigated at the suppliers end and was reported to be OK. As such the reason for shock load / locking needs to be understood from vehicle application point of view.

CONCLUSION

In this work we identified the main causes of failure by under experiment process of three 1616 CR BS-III and taking photographs and observations also. With the help of these observations & result we found The

causes of failure of gears while it is in operation these are Inclusion cluster consisting of Al_2O_2 and other foreign particle getting entrapped in camshaft and compressor gear mainly responsible in crack formation, overloading of engine and tooth breakage. By applying suitable methodology in its design process, manufacturing process and its operation. We can reduce its failure to some extent.

FUTURE SCOPE

By further testing of this failed gear like – metallurgical analysis, fatigue failure analysis, crack failure analysis, gear tooth contact analysis etc, procedure can be done with help of suitable technique. We can find out exact status of foreign particle and also calculate other reason of failure of this gear.

ACKNOWLEDGEMENT

The author would also like to thank Praveen Singh head of ABC Company, for permitting me to visualization of gear while testing and allow me to taking photographs of failed gear which help to me writing the oveservation of failed gear and allowed to me for publication.

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