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Design Analysis of Lubricating Pump Rotor Shaft for Fatigue

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Abstract:-This paper deals with fatigue analysis of lubricating pump rotor shaft of diesel engine which used at generator set. This analysis is done after failure of pump shaft under warranty period at customer end. After first visual analysis it is concluded that this failures may be pre mature fatigue failure due to under design of shaft. In this paper detail fatigue analysis of shaft is done and results of analysis are verified with experimental and FEM analysis.

I. INTRODUCTION

Lube oil pump is the heart of the engine, which supplies continuously lubricating oil to different parts of the engine components, to overcome frictional losses, wear & tear etc. Lubricating oil pump commonly known as a LOP. It consist various components like gear, rotor, shaft, casting body, casting cover, relief valve etc. Since shaft of lubricating oil pump experience a large number of load cycles during its service life, fatigue performance and durability of this component has to be considered in the design process. Design developments have always been an important issue in the production industry, in order to manufacture a less expensive component with the minimum weight possible and proper fatigue strength with standardization in the design to get in time development easy interchangeability and other functional requirements. These improvements results in lighter and smaller engines with better fuel efficiency and higher power output.

II. LITERATURE REVIEW

An exhaustive literature review is carried out to understand the present practices and theories in fatigue analysis of shaft. A paper by Gautam Das, Ashok Kumar Ray, Sabita Ghosh, Swapan Kumar Das and Dipak Kumar Bhattacharya worked on"Fatigue failure of a boiler feed pump rotor shaft"[2]This paper deals with a detailed failure investigation of a rotor shaft in the boiler feed pump used in thermal power plant. The investigation mainly included chemical analysis, microscopy, fractography, hardness measurement and residual stress measurement. Analysis revealed that the metallization processes was primarily responsible for the failure. There were a large number of defects at the interface where the metallization process was terminated near the fillet. The crack had initiated from one or more such defect areas and then further propagated by fatigue. The mode of fracture was fatigue and the presence of oxides at the base of the cavities at the interface regions indicated that surface preparation was not made properly prior to metallization. A Nichols Portland lubricating pump design manual Version 1.3[3] can clearly say that in what way we can select and design a lubricating pump for a particular application. Using computer modeling and years of testing experience, Nichols Portland engineering teams can determine design and performance parameters – not only for the gerotor, but for the system surrounding it. In this design selection manual, better understanding regarding selection is done. A paper by D. Crivellia, R. Ghelichia, M.Guaglianoa worked on "Failure analysis of a shaft of a car lifts system"[1]The failure of a car lift system can result in severe damage to people and structures. It is important to understand the fatigue behavior of these machines, and, in case of a failure, to understand its causes and the possible solutions to increase safety. In this work the failure of the shaft of one of these car lift systems is analyzed. The possible causes of the failure through design, material, fractographical inspections and finite elements analysis were investigated, and possible solutions to avoid these cases in the future are suggested. A paper by S. Cicero, R. Cicero, R. Lacalle, G. Diaz, D. Ferreno worked on "Failure analysis of a lift gear shaft: Application of the FITNET FFS procedure fatigue module"[4]This paper analyses the failure of a lift gear shaft, which happened when the lift was carrying three people. Fortunately, the safety systems worked and there were no serious injuries, but the authorities demanded an investigation into the causes of the accident. The analysis was performed using the FITNET FFS fatigue module, and improper working conditions have been identified as the major cause of the accident.

III. STATEMENT OF PROBLEM

Complete Fatigue analysis of lubricating pump rotor shaft with the help of theoretical, experimental and FEM method

IV. OBJECTIVE OF THE WORK

The objective of paper is to validate present design of engine lubricating oil pump rotor shaft for fatigue failure. The complete work is carried out with the following steps.

1. Theoretical fatigue analysis of lubricating oil pump rotor shaft.
2. Experimental fatigue testing of lubricating oil pump rotor shaft as per actual working conditions. On available test rig
3. Fatigue analysis of lubricating oil pump rotor shaft using Hypermesh and Msc- fatigue software.
4. Validation and conclusion.

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A. Fatigue Analysis

Introduction: Lubricating oil pump shaft is working under combined torsional and bending condition, so while calculating the fatigue life of the shaft fluctuating stresses at minimum and maximum power consumption of the lubricating oil pump are considered. The expected fatigue life of lubricating oil pump rotor shaft during warranty period of 2 years is considered about 22.9 *10^7cycles as per company nomes.

Calculations

Table 1 Power and force calculations.

Sr. No	Name of calculation	Basic Formulae	Minimum value	Maximum value
1	Power Measurement.(P)	V x I x Cos Ø	0.86 KW	0.91 KW
2	Torque calculation for rotor and LOP gear (Tr and Tg)	P = 2πNT/60	2996.1N .mm	3460N. mm
3	Force calculation of the Rotor			
	Tangential Force of Rotor (Ptr)	T/ PCD of rotor	153.3 N	177 N
	Radial force of Rotor (Prr)	Prt tanθ	55.8 N	64.4N
4	Force calculation of the LOP Gear			
	Tangential Force of LOP Gear (Ptg)	(2 Tg/ PCD)	72.7 N	83.9N
	Radial force of LOP Gear (Prg)	{(Ptg min * tan αn) / Cos Ψ}	28.1 N	32.5N
	Axial Force of LOP Gear (Pag)	Pgt * tan Ψ	26.4N	30.6N

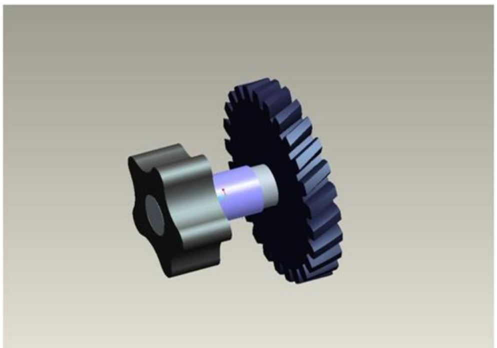

Fig. 1 Rotor and Gear assembly

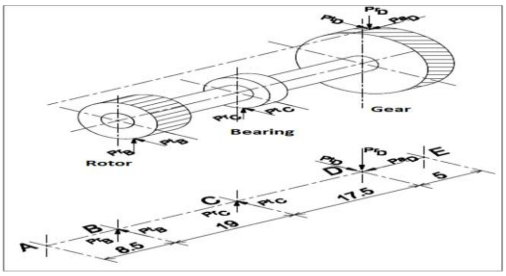

Fig. 2 Force Diagram

Calculation of bending moment

For combined vertical and horizontal bending moment.

Table 2 Bending moment Max., Min., Mean and Variable

B.M. Max.	B.M. Min.	B.M. mean	B.M. Variable
10689.53 N.mm	9255.01 N.mm	9972.27 N.mm	717.26 N.mm

Table 3 Torsional moment.

No	Name	Mini. (N mm)	Max. (N mm)	Mean (N mm)	Variable (N mm)
1	Torsional moment of rotor (Mt_r)	2996.2	3460.6	3228.4	232.2
2	Torsional moment of Gear (Mt_g)	1420.5	1640.7	1530.6	110.09

Table 4 Stress calculations

No	Name of the stress	Mean stress (N/mm2)	Variable stress (N/mm2)
1	Bending stress (σ)	30.11	2.17
2	Torsional stresses (ζ)	4.78	0.35
3	Von Moses Stress	31.23	2.17
4	Design stress	78.18	5.62

Goodman Criteria for Fatigue failure

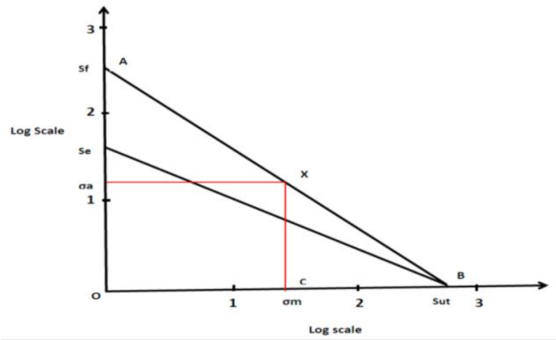

Fig 3 Goodman Diagram

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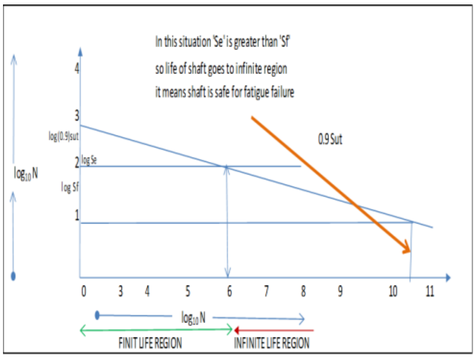

Fig 4 S-N Diagram for shaft.

From the analysis, infinite life of lubricating pump rotor shaft is obtained.

B. Fatigue Life Testing

Test rig

The test rig is manufactured company. It is used to test the pumps by simulating the actual working condition. It is simply made up of the motor and pulley connection to drive the pump. The test rig provides measurement of output flow, delivery pressure, pump rpm and working temperature.

Test rig details

The test rig consist the following components.

Fig 5 Test Rig Assemblies

1. Motor.
2. Flow meter.
3. VFD (Variable frequency drive).
4. Pressure indicator.
5. RPM indicator.
6. Flow control valve.
7. Pump Mounting fixture.

Working of Test Rig:-

The test is carried out as per the company standards on the available test rig.

- Pump back Pressure:- 4.5 kg/cm2
- Oil used:- SAE 40
- Temperature of oil:- 105 ± 50C.
- Minimum speed:- 3250 rpm.
- Maximum speed:- 5000 rpm

Pump is tested by varying speed from 3250 to 5000 rpm for a definite cycle time at 500 hrs. Further radiography testing for crack detection was carried out at NABL (National Accreditation Board for Testing & Calibration Laboratories, India) Lab along with chemical composition and microstructure check.

From the results it is concluded that there is no fatigue failure of lubricating oil pump rotor shaft.

Radiography testing for crack detection

Fig 6 Radiography test machine

Surface crack detection test

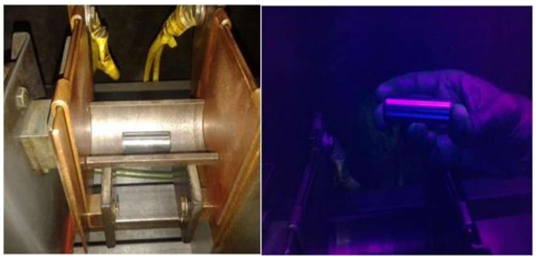

Fig 7 Surface crack test

C. FEM Analysis

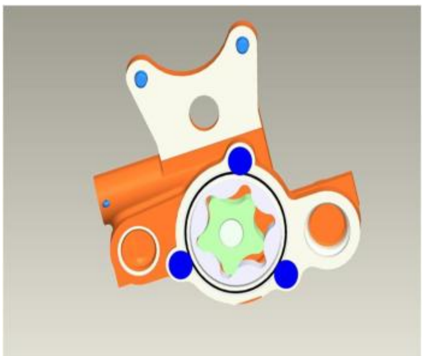

Fig. 8 CAD model of pump assembly

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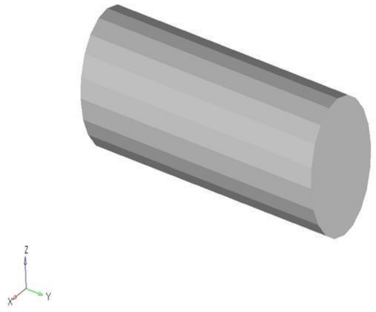

Fig 9 CAD model of shaft

Used brick mesh for Shaft.DOF 1,2,3,4 and 6 were restricted at bearing location for boundary condition Material with mechanical properties closest to the given material is selected from the fatigue material database and used for life prediction.

The software's used and methodology used for analysis.

- Combine vertical and horizontal loading condition.
- Pre-processor- Hyper mesh.
- Solver – Optistruct.
- Post-processor – Hyper view
- Fatigue software – Msc.Fatigue

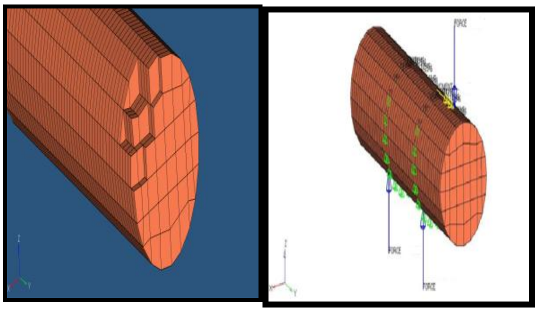

Fig 10 FEM model Results from FE analysis

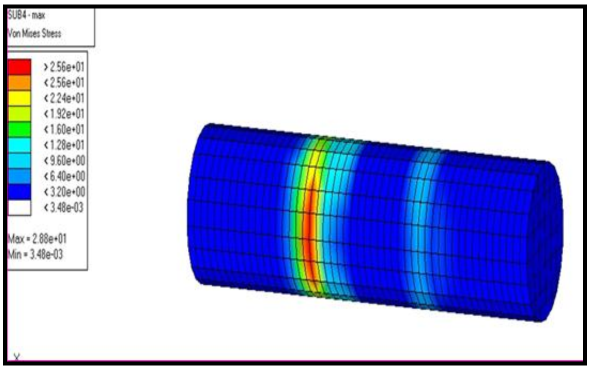

Fig 11 Stress distribution

Fatigue life estimation

Fatigue life of the pump rotor shaft is obtained by using MSC- fatigue software. The result indicates that for 2000000 cycles there is no initiation of crack.

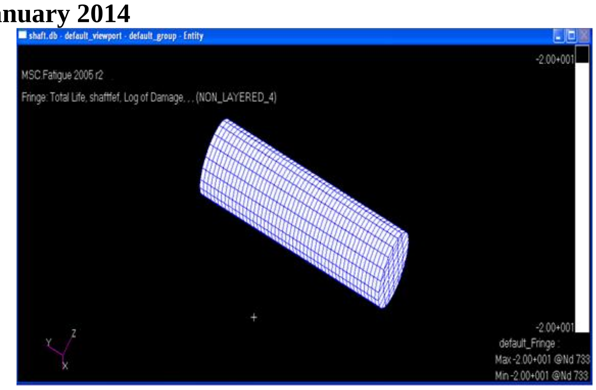

Fig 12 fatigue life of shaft

- Maximum stress observed is 28.8 MPa.
- Fatigue life obtained is more than 2000000 cycles (infinite life).

V. CONCLUSION

The fatigue analysis of lubricating pump rotor shaft is carried out.

It is concluded from the results:-

- Maximum Von Moses stresses obtained by theoretical analysis is 33.395 N/mm^2
- Maximum Von Moses stresses obtained by FEM analysis (Hyper mesh) is 28.8 N/mm^2.
- The fatigue tests conducted, for the expected fatigue life, has resulted in no crack detection which is confirmed by radiography testing.
- Infinite fatigue life is observed by all the results.

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2. Handbook of mechanical design- Thomas Brown.