Design and Durability Analysis for Engine Gear Train

Mahesh B. Bhosle, S.B. Sanap, N. P. Gokhale

***Abstract*— Gears are one of the important elements in the engine. Gears are used to transmit power or torque from one shaft to another shaft. The design of the gears should be such that it is durable. While designing the gears, it should be safe in pitting and bending strength. The gears are used to change the torque and speed. In this paper, helical gears are designed for engine gear train which transmits the power from crank shaft to cam shaft, Fuel injection pump and lubrication oil pump. ISO 6336 standard is used for gear design. The performance of engine gear train is checked with durability test on engine gear train. The gears are achieved their successful life after that moderate wear and polishing wear are observed on gear tooth surface.**

***Index Terms*— Gear, Power, Moderate wear, Polishing wear.**

I. INTRODUCTION

Gears are used from many years to transmit power. The helical gears are used in engine gear train, which is used to transmit power from crank shaft to cam shaft, fuel injection pump (FIP) and lubrication oil pump (LOP). While designing the engine gear train the gear ratio and center distance are important parameters for proper running of the engine. The failure of engine gear train causes the stoppage of the engine, which is not preferable any way. Three component are running by engine gear train which are cam, Fuel injection pump, lubrication oil pump gear but the auxiliary part like air compressor, water pump can be added in engine gear train as per requirement of engine.

The gears are designed for four cylinders and four valve engine. To start the design power calculation is an important parameter, because how much power should transmit the gears without failure. The module is selected from ISO 54 [1].The gears are designed by ISO – 6336 [2-5] standard. According to standard the gears are designed against bending and surface pitting failure. To check the performance of the engine gear train, the durability test is conducted. The durability test is conducted for 500 hours. After durability test moderate wear and polishing wear are observed on gear tooth surface.

II. LITERATURE REVIEW

V. Moorthy and B. A. Shaw [6], had carried out the work on contact fatigue performance on helical gear using surface coating method. In this study gears are coated with Balinit C1000, Balinit C*, CrN + IFLM, C6 + IFLM and Nb–S coatings. Endurance test performed by back to back test rig at two contact stress levels for micropitting and average gear tooth profile deviation. Results obtained shows that Balinit C gives best result for micropitting followed by C6 + IFLM and Nb–S coatings. The lowest profile deviation was shown in gears which are coated with Nb–S coating followed by Balinit C. Other coatings were not showing sufficient performance for micropitting and average gear tooth profile deviation. Overall best result is shown by Nb–S coating.

I.S. Al-Tubi et al. [7], had carried work on gear micropitting initiation and propagation under varying loading condition. In concern study includes both experimental gear testing and analytical evaluation using ISO technical report of gear micropitting, ISO/TR 15144-1:2010 and revised ISO/TR 15144-1:2014. In experimental testing initiation and propagation of micropitting has been found out by using step up torque levels. Experimental result has been validated by using analytical evaluation. It is found that micropitting starts at pinion dedendum and increases at addendum. Analytical results confirm the maximum contact stress and minimum specific lubricant film thickness occurs in this region.

M. Amarnath and Sang-Kwon Lee [8], had carried out work on spur gear for surface contact fatigue failure based on tribological and vibrational parameters. The experiment was carried out for single stage gear box. Due to changes in operating condition like temperature, load and reduction in viscosity of oil, failure on tooth surface occurred. It is found that after 200 hours small micropits are observed, after 400 hours micropitting is appeared on adjacent tooth, after 800 hours scuffing is appeared and after 1200 hours scoring is appeared on gear tooth surface.

Samroeng Netpu and Panya Srichandr [9], had carried out work on failure of helical gear in power plant. The gears were used in gear box which drives the generator. The gears failed after nine years. The visual, macro and microscopic examination were performed on fracture surface of gear. The result showed that the fatigue fracture characteristics exhibited by fracture surface. The inclusions were found in microstructure of gear material. The inclusions are iron oxide surrounded by (FeMo)3C carbide. The fatigue crack developed at inclusion a propagated in gear tooth up to its failure.

III. ENGINE GEAR TRAIN

The transmission of power from input shaft to output shafts is done by the gear train. In engine gear train, the transmission of power is from crank shaft gear to cam shaft gear, FIP gear and LOP gear are the main concern to run the engine. Due to large center distance the intermediate gears are used.

Mahesh B. Bhosle, Department of Mechanical Engineering, Sinhgad College of Engineering, Pune. (e-mail: bhoslemahesh13@gmail.com).

S. B. Sanap, Department of Mechanical Engineering, Sinhgad College of Engineering, Pune. (e-mail: sbsanap.scoe@sinhgad.edu).

N. P. Gokhale, GM, Kirloskar Oil Engines Limited, Khadaki, Pune. (nitin.gokhale@kirloskar.com)

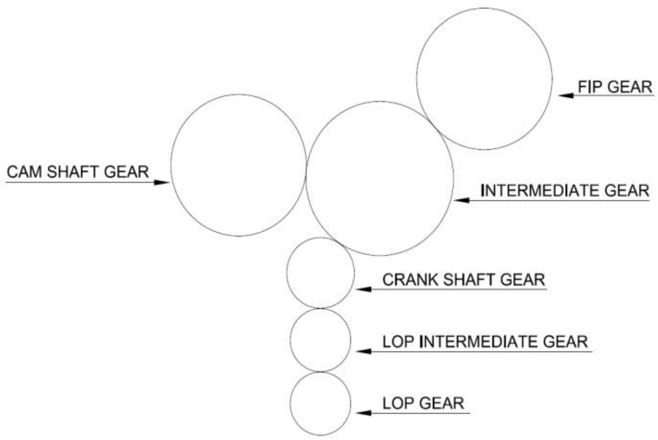

Fig 1. Engine gear train

Fig 1 shows that engine gear train transmit power from crank shaft gear to cam shaft gear through intermediate gear similarly for fuel injection pump gear. The lubrication oil pump gear also drives from crank gear via intermediate gear.

IV. POWER CALCULATION FOR ENGINE GEAR TRAIN

The calculation of power for engine gear train is important because on which the whole gear design is dependent. The crank shaft should provide the power for cam shaft, fuel injection pump and LOP. The power required for cam shaft is maximum at exhaust stroke, because the piston in cylinder pushing the gases outside but exhaust valve should be open. While calculating power required for cam shaft, the exhaust blowdown pressure [10] is very important parameter. Cam shaft worked against this force. The power for cam shaft can be calculated by equation (1).

$$P_{CAM} = \frac{p_b * (\frac{\pi}{4}) * d_c^{\ 2} * RR * v_{cam} * 2}{\eta_1} \tag{1}$$

The fuel injection pump is required to drive the diesel engine. Fuel injection pump is used to pressurize fuel and send it to the injector. As the injection pressure increases the power required for driving the fuel injection pump also increases. In the engine gear train the power required for fuel injection pump is larger than cam shaft and LOP. The delivery pressure of fuel injection pump is major factor for calculation of power. The power for FIP can be calculated by equation (2).

$$P_{FIP} = p_d * (\frac{\pi}{4}) * d_{FIP}^{\ 2} * v_{camFIP} \tag{2}$$

The lubrication oil pump is used to pump in lubricating oil to all rotating parts in engine from oil sump. The oil will flow in all part of engine like bearings, gear train, valve train, piston cooling nozzle. If proper lubrication is not provided then engine component fails. While calculating the power required for lubrication oil pump delivery pressure and discharge of lubrication oil pump are the main parameters. The power required for LOP can be calculated by equation (3).

$$P_{LOP} = \frac{p_{dl} * Q}{\eta_2} \tag{3}$$

V. MODULE AND NUMBER OF TEETH SELECTION

The module selection and number of teeth selection are depends on center distance between crank shaft, cam shaft, Fuel injection pump and lubrication oil pump. It is based on layout of engine. While selecting module and number of teeth along with center distance the gear ratio is also maintained, because if any parameter goes wrong total failure of engine takes place. The module is selected from ISO 54 [1], the module selected for engine gear train is 2.5 mm.

VI. SURFACE DURABILITY AND BENDING STRENGTH

The basic calculation of contact stress is Hertzian pressure. This gives contact stress generated during tooth flank engagement. The contact stress is not the only cause of pitting some other parameters like coefficient of friction, sliding velocity, lubrication are also responsible for pitting. At the mating flank if surface durability exceeded then particle present on flank brakes out and forms pit on the surface[3].

The maximum tensile strength at the root of the teeth it may not exceed the permissible bending stress of the material. Stresses are developed in tension fillet while gear is running but the crack developed in the compression fillet and propagate towards tension fillet which is failure of teeth. Tooth breakage ends the service life of the gear [4].

VII. DURABILITY TEST

Durability test is conducted to check the performance of engine gear train when it is fitted with engine. The test is carried out on engine test bed. The test is conducted in the laboratory and all the engine performances are under monitoring. The test conducted is accelerated durability test. The test is conducted for 500 hours.

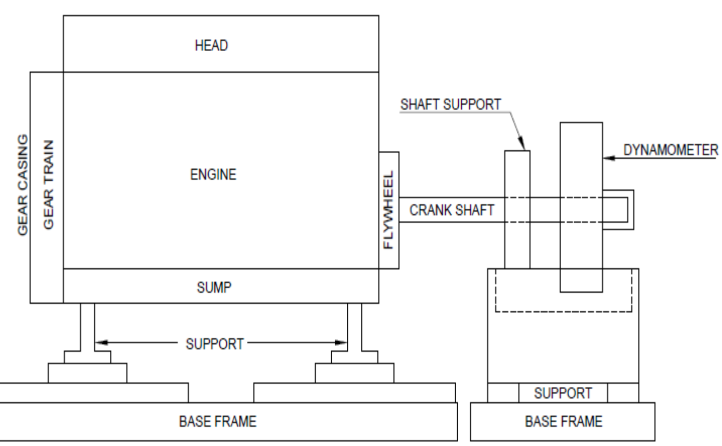

Fig 2. Block diagram of experimental Setup

The experimental setup consists of engine with which all the gear train is fitted. To apply load on engine gear train the dynamometer is fitted to crankshaft. The engine is fitted on test bed. Engine was run for full load for 500 hours. The experimental setup is showed in Fig 2.

VIII. RESULTS AND DISCUSSIONS

The transmission of power from one shaft to another shaft is done by gear train. The transmission of power from crank shaft to cam shaft, FIP, LOP is done by engine gear train. The design of gears is done by ISO 6336 [2-5] standard. From center distance, gear ratio and engine layout the module and number of tooth are selected as shown in TABLE 1. The module is selected from ISO 54 [1]. The selected module is 2.5 mm.

TABLE 1
Result table of gear specification

Gears	Z	m_n (mm)	α, β (degree)
Crank	28	2.5	20
Intermediate	61	2.5	20
Cam	56	2.5	20
FIP	56	2.5	20
LOP intermediate	25	2.5	20
LOP	25	2.5	20

Fig 3 depicts the graphical representation of the different values of power and factor of safety (FOS) against pitting. By considering the power transmission capability of each and every gear of the gear train , it can be seen there is gradual increase in FOS from crank to FIP and further values are fluctuates with little margin for FIP, cam and LOP respectively.

If power is considered, the power transmitted by the crank is large. As the FIP and cam are driven by the same intermediate gear, the input power for both of them is same. For LOP gear power transmission is least with respect to other gears of the gear train.

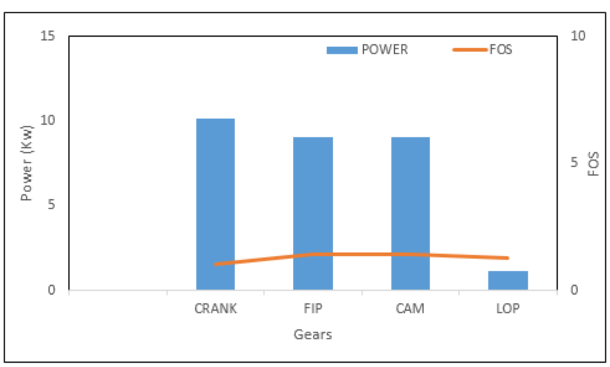

Fig 3. Graph for power vs. factor of safety against pitting

The FOS in bending is more than that of the pitting hence it can be said that the gear train is safer in the case of bending strength. The durability test is conducted on engine gear train. The results are shown in Fig 4 and 5 for one gear pair in engine gear train. The observations are made by referring ISO 10825 [11] and as follows,

As shown in Fig 4, after 500 hours on pitch surface the lines are present. Moderate wear is observed on the gear tooth surface.
The irregularities are present on gear tooth surface, when it comes in contact mirror like smooth surface is produced. It is slow wearing process. As shown in Fig 5, after 500 hours it is observed to be a polishing wear.

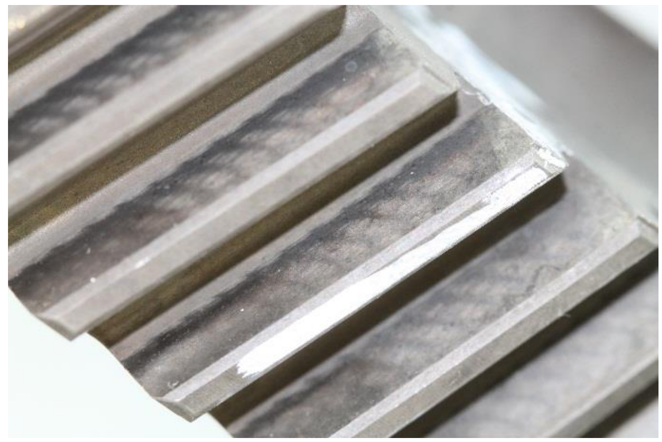

Fig 4. Moderate wear after 500 hours.

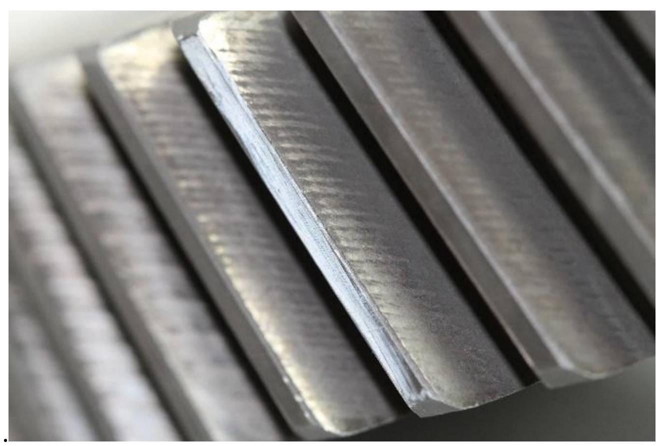

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Fig 5. Polishing wear after 500 hours.

IX. CONCLUSION

The engine gear train used for the transmission of power from input shaft to output shaft. In the experimentation, durability test is conducted on engine gear train. The test was conducted for 500 hours and the observations were made for one gear pair. On one gear moderate wear is observed. On other gear due to presence of irregularities at the contact point smooth and mirror like surface finish is produced which shows polishing wear.

TABLE 2
Nomenclature

Symbol	Parameters	Unit
Z	Number of teeth	-
m_n	Normal module	mm
α	Pressure angle	degree
β	Helix angle	degree
p_b	Exhaust blowdown pressure	N/m^2
d_c	Diameter of exhaust valve seat	m
d_{FIP}	Diameter of piston in FIP	m
RR	Rocker ratio	-
v_{cam}	Instantaneous velocity of cam	m/s
η_1	Efficiency of cam	-
η_2	Efficiency of LOP	-
v_{camFIP}	Instantaneous velocity of cam in FIP	m/s
p_{dl}	Delivery pressure of LOP	N/m^2
Q	Discharge of LOP	m^3/s
P_{CAM}	Power of cam	W
P_{FIP}	Power of FIP	W
P_{LOP}	Power of LOP	W

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