"LUBE OIL CONSUMPTION ANALYSIS OF DI ENGINE USING RICARDO RINGPAK SOFTWARE"

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ABSTRACT

As the emission standards have become stricter, in recent years, the diesel engine technology has continued to advance rapidly in the field of emission control. The focus of engine industry research and development is on reducing the engine out emissions CO, HC, NOx and particulate matter (PM).

The particulate matter in the air has become the subject of increased attention due to concern of potential health effects. To meet the ever-demanding needs to reduce PM, lube oil consumption reduction is one of the effective ways. Therefore, it is necessary to better understand the effects of ringpack parameters on engine lube oil consumption.

In order to evaluate and or optimise the ringpack performance, a parametric study of ringpack is carried out using Ricardo RINGPAK ver. 3.1.1 simulation package.

This simulation package uses a completely integrated approach through the intricate coupling of various sub models which include ring axial and twist dynamics, inter –ring gas dynamics, lubrication module, oil consumption, ring conformance etc.,

The ringpack model of DI engine is prepared in the pre –processor of the RINGPAK, which consists of piston land profile, groove profile, ring profile with all geometrical data along with the material properties and surface finish.

The effect of the top ring end gap and engine speed on oil consumption, wear rate of ring and liner face and power loss in friction were studied for reduction of oil consumption.

The oil consumption was predicated using the existing ring configuration with the bore distortion and model was tuned to match the measured oil consumption values. The sensitivity study was done to reveal the trend of oil consumption with top ring end gap increase and engine speed.

The results were obtained for each iteration of ringpack parameter; in the form of inter-ring gas pressures, ring-liner minimum oil film thickness, maximum instantaneous ring pressure and ring displacement. From the results of oil consumption, it was seen that the top ring end gap increase has the positive effect on the reduction of oil consumption. The ring displacement prediction gave no indication of either the ring flutter or ring sticking during the complete engine cycle. Similarly ring –liner minimum oil film thickness plot was useful to make sure that ring is not operating in the oil starved or fully flooded condition.

Hence from the sensitivity analysis of ringpack, it was possible to optimise the ringpack configuration.

INTRODUCTION

Piston rings in a piston engine play an important role in the performance and endurance of the engine. Piston rings have to provide optimum sealing function, low wear and friction all at the same time. The lube oil consumption and blow-by in an engine is directly related to the sealing function of the piston rings.

The need to meet stricter emission norms demands reduction in the lube oil consumption because lube oil consumption has very high impact on the emission of the particulate matter from diesel engine. Achievement of low oil consumption is sometimes a matter of trial and error method. The better way to understand the piston ring dynamics and complex phenomenon of gas dynamics; is to use a simulation tool having a fair degree of accuracy to prepare a model of the piston, piston rings and liner for analysis. Ricardo's RINGPAK software was used as a simulation tool for investigating the lube oil consumption and ring dynamics in the existing DI engine ring pack configuration.

RINGPAK SOFTWARE

RINGPAK consists of basically two modules one is RINGPRE (Pre-processing plus solver) and the other is RINGVIS for post processing. The pre-processor module RINGPRE generates the input data file for simulation purpose.

The solver is a complex integration of the following sub models,

1) Ring axial and twist dynamics
2) Inter-ring gas dynamics
3) Ring radial dynamics
4) Lubrication modules (Hydrodynamic, Mixed and Boundary) at the ring-liner interface
5) Liner oil transport
6) Oil consumption
7) Ring face and liner wear
8) Ring conformance

The solver calculates the results as a function of,

1) Piston ring pack configuration/geometry
2) Material properties of the components
3) Surface finish parameters of the components
4) Lubricant properties
5) Engine operating condition (example speed, cylinder and crankcase pressures and temperatures)
6) Piston/Ring/Liner temperatures
7) Distorted bore shape

MODELING

The modeling part of the pre-processor mainly consists of defining land profile points for piston geometry, grooves, ring and ring face. The land profile co-ordinates were used to model the piston and grooves. The modeling of the piston rings was done by specifying the cross sectional dimensions and then the face profile. The face profile can be specified in two ways, one by specifying the profile points and second one is by parametric method i.e. by using curves and bevels. The second method was used for modeling face profile of the rings as the rings face profile can be easily generated in the model and can be converted into ring profile points.

The following were the input requirements,

1) Engine features (e.g. Bore, stroke, connecting rod length, speed)
2) Land and groove geometry
3) Ring geometry and ring face profile
4) Surface roughness features of rings, grooves and liner
5) Lubrication properties of oil (e.g. viscosity, density, distillate fractions)
6) Temperatures of surfaces
7) Cylinder pressure and temperature
8) Oil supply information
9) Distorted bore shape

The geometric data and material data for the piston land, groove and the rings were taken from the component engineering drawings. The ring face profile was modeled using the parametric option, i.e. by using curves to model the face barrel. The oil of grade SAE 30 was used for the analysis. The software has a data bank for most of the commercial oils. In addition the RINGPRE also has a facility for user defined oil data input. The P-Theta diagram is specified at the simulation speeds.

The surface roughness and the hardness data for the land, grooves and rings were obtained by measurements in the Metrology and the Metallurgy laboratories.

SIMULATION RESULTS

The effect of engine speed on the oil consumption is shown in Fig.1. It is observed that with increase in

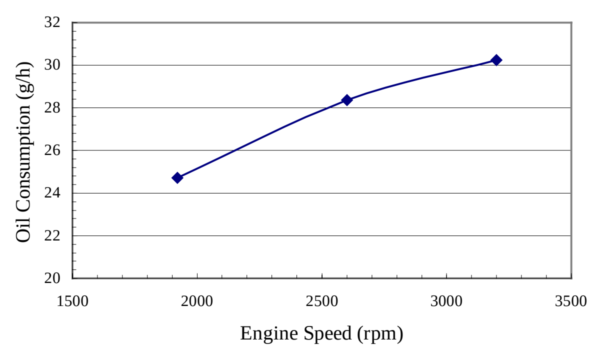


Fig. 1.0., Effect of Engine Speed on Oil Consumption

the engine speed the oil consumption increases almost linearly.

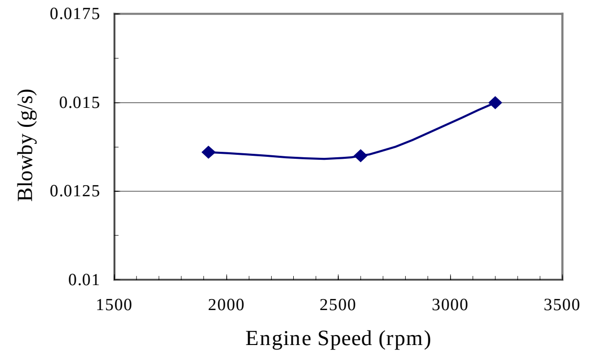


Fig.2., Effect of Engine Speed on Blow by

This is primarily due to increase in the number of cycles per hour with the increase in speed. Also the inertia effects are more dominant at higher engine speeds. The trend of the blowby is as shown in Fig.2

OIL CONSUMPTION

The total oil consumption phenomenon consists of the oil consumption due to oil throwoff from the top ring into the combustion chamber, blowback and evaporation. Throw off from the top ring has a major share on the total oil consumption for a given set of conditions. Fig.3 shows the comparative mechanism of oil consumption contributing to the total oil consumption. The oil consumption data plotted above corresponds to full load condition at that engine speed.

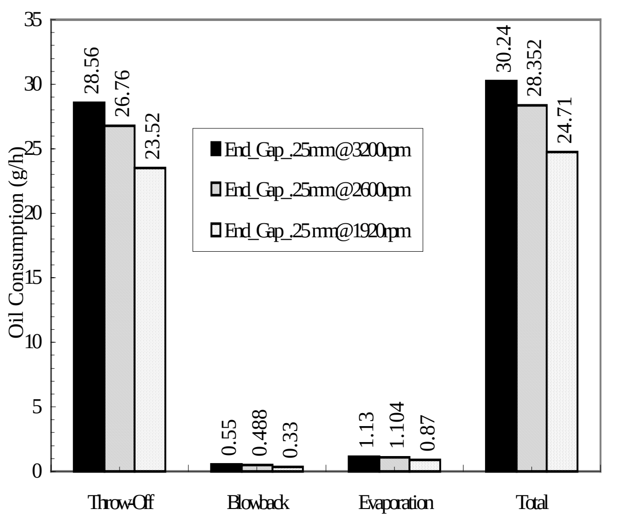


Fig.3., Modes of Oil Consumption

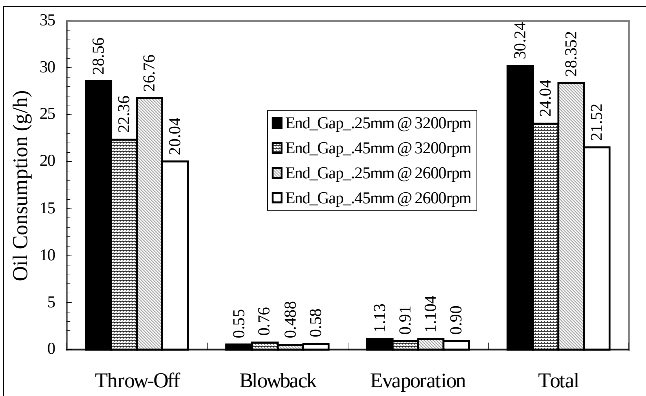


Fig.4., Effect of Top Ring End Gap on Oil Consumption

Effect of Top Ring End Gap

Traditionally it is experienced that the increase in the top ring end gap helps in reducing the oil consumption. The cause of reduction is the decrease in the oil throw off due to reduction in the circumferencial oil accumulation area. This reduces the oil reaching the combustion chamber, due to less oil accumulation. The effect of top ring end gap is shown in Fig.4. Changing the end gap from 0.25 mm to 0.45 mm gave an improvement of 20% at 3200 rpm.

The improvement in the oil consumption due to increase in the top ring end gap has two sides, when the top ring end gap is increased, for a given speed and load setting, cylinder pressure values decrease. This is due to the fact that during the compression stroke, as the piston is coming up, the compressed gases start flowing through the enlarged end-gap, thus leading to a lower volume of gas available for combustion. This results in lower cylinder pressures.

However, for the same given speed and load setting, since more gases are flowing into second land region, the second land pressures are higher with increasing top ring end gap sizes.

Consider the situation during expansion stroke, when the cylinder pressure values start dropping below the second land pressures, there is a reverse flow of gases leading to entrainment consumption mode. With increasing end gap sizes; there are higher second land pressures and lower cylinder pressures, and in general one would expect to see slight increase in entrainment oil consumption value since there are higher reverse gas flow rates during expansion.

The other is effect is that, since the cylinder pressures are lower with increasing end gap sizes, the gas loads acting behind the top ring are lower and hence, the top rings has lower scraping action and accumulates less oil. Thus the throw off oil consumption value could be expected to be lower with increasing top ring end gap size. Since the accumulated oil is also a source of entrainment mode (coupling between the 2 modes), this can have the decreasing effect on the entrainment mode.

For a given speed and load condition and increasing end gap size, cylinder pressure drops, second land pressure increase, reverse gas flow-rates through the end gap increase, oil accumulation at the top ring leading edge decrease (throw off drops). Although reverse gas flow rates increases, source of oil may be lower (entrainment has a balancing act; could increase but typically decreases)

Thus in general oil consumption should be lower with increase in top ring end gap size but in some cases of high oil availability could show a slight increase due to above reasons. The case of DI engine illustrated here has an effect of decrease in oil consumption with the increase in top ring end gap which is experimentally validated.

Ring –Liner Lubrication

The lubrication module in the software predicts; the minimum oil film thickness prevailing between the ring and liner throughout the engine cycle.

The Fig.5 gives the minimum oil film thickness variation for complete engine cycle. Generally the first ring is more critical for the oil film thickness

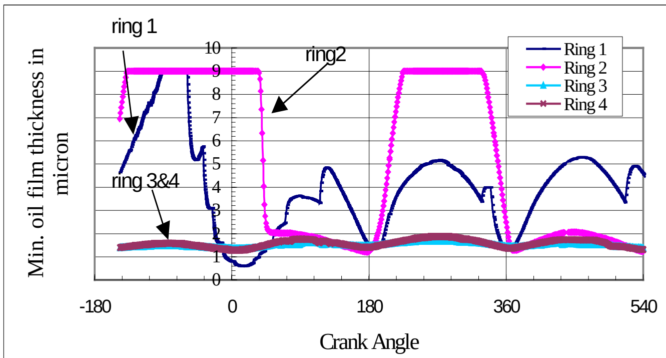
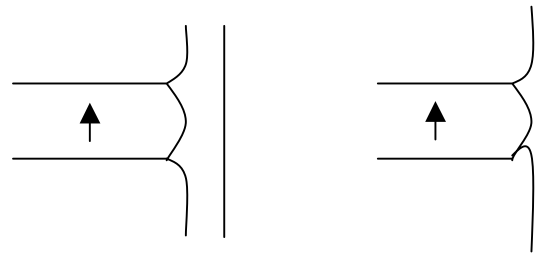
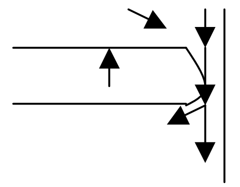


Fig. 5.,Minimum Oil Film Thickness

because it encounters the maximum pressure rise during the combustion. The ring operation should be such that there should not be metal to metal contact between the liner and ring face as it will lead to very rapid wear of the ring. The ring liner lubrication regime can be divided in three categories a) Fully flooded ring, b) Partially flooded ring and c)Completely starved ring. All the mentioned conditions of the rings are shown in Fig.6.



a) Fully Flooded ring b)Partially flooded ring



c) Fully starved ring

Fig.6, Regimes of ring – liner lubrication

In fully flooded ring the entire ring face is lubricated by oil and the loads are borne by oil film and asperity forces only. Whereas in the partially flooded ring only a fraction of the ring face is lubricated by oil, with remaining portion being gas lubricated. As a result loads are borne by oil/asperity forces and gas forces. This is the preferred regime of lubrication, which ensures no accumulation of oil as well as no metal to metal

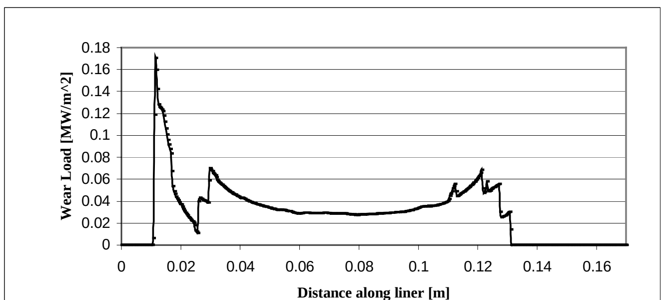


Fig. 7 Wear along Liner

contact. Consider third situation, this condition happens due to low lubricant availability on the liner or a high pressure gradient across the ring. This leads to detachment of oil film from the ring face. The loads on the ring are supported by only the gases flowing below the ring face. In this condition metal to metal contact occurs and will lead to excessive gas blow-by or high wear rate of ring face. From Fig. 5 it is seen that for the existing condition there is no metal to metal contact taking place; hence wear can be expected within the durability limit. The Fig. 7 shows the graph of wear across the liner span.

The wear load as seen from Fig. 7, is maximum at the TDC position; due to combustion . Thus higher wear rates are expected at this position due to reversal of direction of motion of top ring and in addition to this high –pressure values also contribute to this effect.

Ring Flutter

The phenomenon of ring flutter is more prone to the fully starved condition of lubrication due to high pressure gradient across the ring. Since from the minimum oil film lubrication graph, it was stated that the rings are operating in partially flooded lubrication regime, and again this can be made sure from the ring axial movement plots as given in Fig 8. There are no discontinuities or shattering in the axial movement graphs, it can be firmly said that

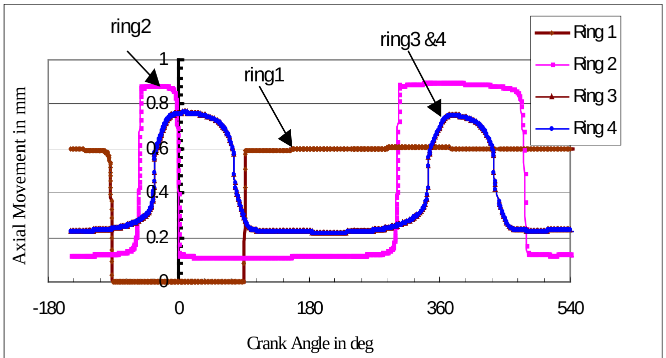


Fig. 8, Ring Outer Dia. Axial Movement

there are no signs of ring flutter throughout the engine operating cycle.

EXPERIMENTAL VALIDATION

The oil consumption test was done on the engine with the increased end gap of 0.45mm the results obtained shows the close matching with the predicted oil consumption with the software in the accuracy of around 8 to 10 % at 3200 rpm. The accuracy of the results is also attributed to the input data of the software, which is a critical parameter to govern the prediction.

CONCLUSION

The simulation model developed using software RINGPAK gave an insight of the performance parameter of the ringpack for the existing direct injection diesel engine configuration.

- The oil consumption increases with the increase in engine speed as the same way blow –by also shows an increasing trend. The oil consumption increases by 16.5% from engine speed of 1800 to 2600 rpm and also shows an increase by 7% from engine speed of 2600 to 3200 rpm. It is clear that the rate of increase of oil consumption falls with the increase in the engine speed.
- Oil- throw off from the top ring has the major share in total mechanism of oil consumption
- There is no oil starvation during the complete operating cycle of the engine this avoids the metal to metal contact throughout the engine operating.
- With an increase in the top ring end gap, it is seen that the oil consumption has come down. The change of top ring end gap from 0.25 to 0.45 mm gave an improvement of 20% at 3200 rpm and at around 24% at 2600 rpm.

ACKNOWLEDGEMENT:

The authors would like to express sincere thanks to Dr. P. K. Goenka, Vice President (R&D), Mahindra & Mahindra Ltd., Ricardo Consulting Engineers Uk, and Management of Mahindra & Mahindra Limited for their support and guidance to publish this paper.

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