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Research Article

Effect of Cylinder Head Bolt Preload on Piston Ring Conformability and Engine Blow

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Abstract

The project work is concerned with the application of mathematical model, piston ring dynamics software and experimental investigation for the prediction of the piston ring conformability of the cylinder liner bore for the applied cylinder head bolt preload in four cylinder diesel engine for tractor application. The distortion of the cylinder liners of internal combustion engines has a significant effect on engine operation and performance like engine blow by and lubricating oil consumption. In order to control exhaust emissions, engine blow by and fuel consumption, piston ring conformability with distorted cylinder liner have a significant role. The effect of various parameters like engine speed, liner deformation due to assembly load and conformability of the rings have been analyzed for their effect on amount of engine blow by and cylinder bore deformation, the results are studied for different parameter and nature of deformation.

Keywords: *4 Cylinder Diesel Engine, Distortion, Pretension, Piston Ring Dynamics Software, Blow by.*

1. Introduction

The engines are complex to provide cooling path between the cylinder liners. This leads to higher temperature and thermal load in the adjusting area of two liners which lead to increase in the liner deformation. Stricter emission standards have resulted in a need to increase blow by control for heavy duty diesel engines. Therefore, reduction of blow by and lube oil consumption is a major task in the development process of modern diesel engines. To achieve ideal conditions for the function and durability of piston, piston rings and liner, the shape of the piston liner should be as circular as possible, due to different operating, manufacturing and assembly necessities the liners differ from the ideal geometry.

If the preload is high, can cause blow by. Blow by gases generally flow from the gaps between cylinder liner and piston rings. These gases, once in the engine crankcase, are loaded in an oil aerosol. Blow by gases cause problems with possible risks to the engine. The parameters affected are loss of compression, loss of fuel economy and can contribute to oil consumption. If preload is less, there will be loosening of bolt and leakages of combustion gases, lubrication oil, coolants can take place.

2. Literature review

A methodology to estimate bore distortion was introduced. The procedure that could be used to evaluate the cylinder bore distortion due to clamp of head bolt, engine thermal load, and engine firing conditions were discussed (Amir Ghasemi, 2012). The maximum deformation that a ring can conform to were calculated using different equations. Based on these a semi empirical equation was proposed to calculate the limit of piston ring conformability (Eduardo Tomanik, 1996). The Fourier coefficients of a distorted cylinder bore was calculated which characterize the deformed bore orders. The effect of each order on total lube oil consumption was investigated by means of the oil consumption model (Franz Maassen *et al*, 2001). The Cylinder Bore Distortions and the part they play in affecting oil consumption, blow by and emissions and also the overall performance of an engine were discussed. The idea and method used in a Microsoft Excel based program, the Bore Analysis Tool, would provides a relatively quick, simple and cheap method of recording large amounts of data on harmonic distortions of cylinder bores (Paul Gibbs (2001)). The distortion levels in the block due to clamping loads were used to measure with FEA analysis using CAE tool ANSYS and were checked by the experimental data. The causes of distortion and their affects were studied. (Pratik B Mirajdar *et al*, (2013)).

This paper is concerned with cylinder bore distortion, which affects the oil consumption, blow by and emissions, are of great significance to the overall performance of an engine. They are however, difficult to measure and the results are often open to

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interpretation. Mathematical model was developed by classical method which gives the distortion plot more easily and faster. Piston and ring dynamics software is used to calculate the behavior of piston ring conformability and further experimental investigation would be carried out to validate the result.

2.1 Objective

The objective of this project work is mainly focused at building up the methodology for prediction of piston ring conformability through mathematical modelling and its effect on piston ring dynamics and engine blow by. The results are validated with the experimentation.

2.2 Scope

- To determine the distortion levels in the cylinder liner block due to clamping load.
- To get the piston ring conformability to a distorted cylinder bore.
- To investigate the blow by through piston ring dynamics software.
- To validate the simulation results through experimentation.

2.3 Methodology

- Mathematical modelling for conformability of the piston rings to the distorted cylinder liner.
- Study of Fourier harmonic analysis to get the maximum diametric amplitude of the cylinder liner.
- Piston and ring dynamics software used to predict the engine blow by.
- Experimental investigation considering the engine blow by would be done to validate the results.

3. Preload on Cylinder Head Bolt

Preload is estimated based upon peak cylinder pressure, number of bolts around cylinder and type of cylinder head gasket. For current application preload is applied 75.3 KN and piston ring conformability is estimated.

4. Piston Ring Conformability

Conformability is defined as the ability of a piston ring to conform to a deformed cylinder bore. Different equations given by Dunaevsky, Muller and Tomanik were used to calculate the piston ring conformability. These equations do not consider the ring end gap, ovality, gas pressure acting on it, nor the actual bore shape. The maximum diametrical amplitude refers to the maximum deviation across the bore that the ring would be able to conform to.

The gaps between the piston, piston rings, and cylinder wall are shown schematically in Fig. 1. These crevices consist of a series of volumes connected by flow restrictions such as the ring side clearance and ring gap. The geometry changes as each ring moves up and down in its ring groove, sealing either at the top or bottom ring surface.

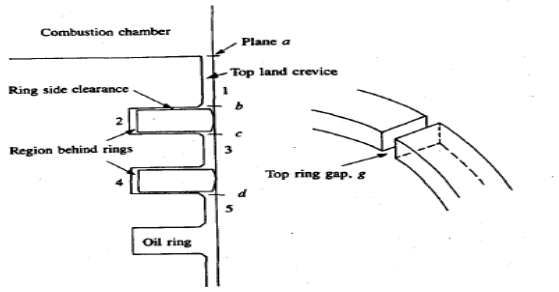

Fig.1 Schematic of piston and ring assembly in automotive engine

The ring capacity to conform to a deformed bore depends on several design factors. Some of them can be joined in the k parameter called as the "conformability coefficient".

$$k = \frac{F_t \times D_n^2}{4 \times E \times I} \quad (1)$$

Where,
F_t : Ring tangential load (N)
D_n : Ring nominal diameter (mm)
E : Modulus of elasticity (N/mm^2)
I : Moment of inertia of the ring cross section (mm^4)

Usually k values for compression ring are between 0.02 and 0.04; oil rings have higher k values. A higher k value means a higher ring capacity to conform to deformed bores.

The conformability criterion made by Tomanik and the maximum diametrical amplitude (Umax) that the ring can conform to is given as

$$Umax = \frac{k \times r}{10(i^2-1)} \quad (2)$$

Where,

k : ring conformability coefficient
r : ring radius
i : deformation order (i = 2, 3...)

Fig.2 The conformability criterion given by Tomanik

If the bore deformation surpasses the ring conformability the percentage of ring periphery contacting the bore can be estimated. The conformability obtained using Tomanik criterion results in the lowest minimum clearance which yields the worst case scenario. The criterion given by Muller overestimated ring conformability for deformations of order two whereas, Dunaevsky criterion greatly overestimated conformability for all orders.

5. Fourier Harmonic Analysis of Bore Distortion

The bore distortion analyses in engines have some features to be quantified such as roundness, eccentricity and cylindricity. To analyse these features, a mathematical model is considered to provide easy access to these distortion parameters. A simple and common method for determining the magnitude of distortion is to evaluate the radial difference between inscribed and circumscribed circles in a distorted bore. However, there is an alternative procedure to calculate deviation from ideal circle, with a Fourier series.

$$F(t) = a_0 + \sum_{n=1}^{\infty} (a_1 \cos(\Theta) + b_1 \sin(\Theta)) \quad (3)$$

The Fourier coefficient can be numerically calculated by:

$$a_0 = \frac{2\sum y}{N} \quad (4)$$

$$a_1 = \frac{2\sum y \cos\Theta}{N} \quad (5)$$

$$b_1 = \frac{2\sum y \sin\Theta}{N} \quad (6)$$

Where: a_n and b_n are the Fourier coefficients of order n; Θ is the angle between 0^o and 360^o.
Amplitude of n^{th} order harmonic is given as

$$c_n^2 = a_n^2 + b_n^2 \quad (7)$$

In general, the distortion pattern is sufficiently represented by the first five terms of the series. The coefficient of a_0 which is the 0^{th} order is the variation of bore radius.

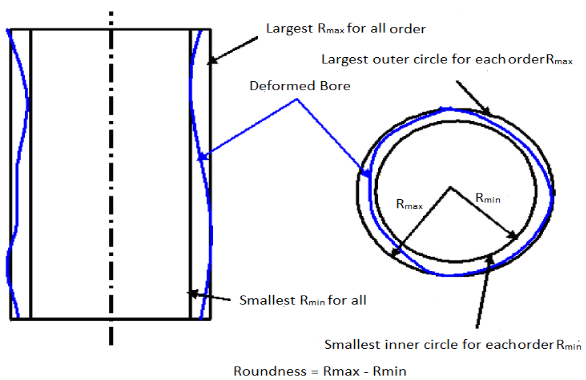

Fig.3 Roundness for cylinder bore

The distortion causes a regular sinusoidal deformation in the cylinder, which can be obtained mathematically from measurements of the surface of the cylinder. The 'harmonics' can be defined as the building of the real shape from the combination of many sinusoidal waves of different orders.

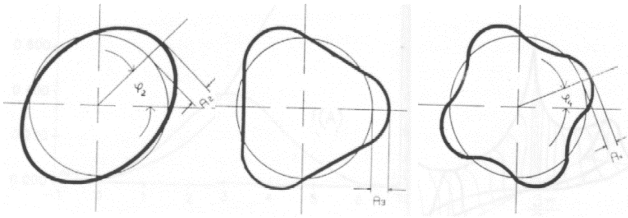

Fig.4 A sample second, third and fourth order distortions are displayed in the above figure

A first order distortion appears as an offset of the whole section from the main axis, second order appears as an 'ovality', third order as a three lobed deformation, fourth as four lobes, and so on. An infinite number of order combine to make up the final shape.

6. Piston and Ring Dynamics Model

Piston rings have to provide optimum sealing function and low wear, all at the same time. The movement of rings is determined by the movement of the piston in the deformed liner on one hand and by the loads on the single ring due to gas, masses, friction on the other. The correct modelling of the physical behaviour of the piston rings under running engine conditions is complex due to the interaction of completely different structures. The three dimensional simulation tool, Piston and Ring Dynamics, is used to analyse the real movement of piston ring position changes in detail. The better understanding of real processes influences targeted optimization measures on the complete piston ring and running surface system level.

The operating behaviour of an engine is significantly affected by the dynamics of the piston rings. Ring dynamics influence blow-by, lube oil consumption and friction losses of the piston liner groove. Therefore the piston ring dynamics model was developed to analyse effects of design modifications of piston and piston rings in view of lube oil consumption, blow-by and friction values.

The result of the piston ring dynamics calculation shows the dynamic components of motion of the single rings in a thrust-anti-thrust side plane. The simulation also gives values for bow-by, inter-ring pressure and oil film thickness between the ring and liner over crank angle.

7. Experimental Setup

The experimental work would be carried out at Automotive Research Association of India Limited (ARAI Pune) on four cylinder inline turbo charged inter cooled diesel engine of 75 HP at rated speed used for agricultural tractors of bore to stroke ratio of 1. Overall ring dynamics configurations would be tested at different engine operating conditions. The engine performance parameters would be taken in addition to the blow-by values.

Conclusion

Increase in pretension load increases the bore deformation of the cylinder liner of both second and forth order component. The forth order component is more sensitive compare to second order component. Focus on second, fourth, sixth order deformation emphasized because these component are critical for piston ring conformability in concern. Pretension in the bolts should be at minimum possible level but it should be sufficient enough to prevent gas leakages.

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