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" A STUDY ON PISTON THERMAL DESIGN"

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ABSTRACT

The piston ring is one of the main companant of an internal combustion engine. Its main purposes are to seal the combustion chamber of the engine, minimize the friction against the cylinder liner but also transfer heat from the piston to the cooled cylinder liner. Another important property of the piston ring is to evenly distribute oil along the cylinder liner in order to avoid engine seizure. There are two types of piston ring: compression ring and oil ring. Automobile reciprocating engines normally use three rings, two compression rings and one oil ring. Piston ring moves freely within its groove. Such movements depend on the forces and the moments acting on the piston ring system such as: the static ring tension from installation of piston ring in the cylinder liner, the gas pressure forces caused by cylinder pressure and blow-by gas, the hydrodynamic forces caused by lubricant film, the inertia forces related to component mass and engine speed, and asperity contact forces caused by a direct contact to the cylinder walls. Working conditions of piston rings are very demanding and it is desirable to understand the design of such component subjected to various loads. Recently, finite element analysis has played major role in automotive industry to design various components of automobile. Hence, this work aims to design and analyze the piston ring using commercial FEA tool like ANSYS. Structural designs of piston rings are not studied adequately. Hence, this work aims to study structural design and analysis of piston rings subjected to static loads.

Keyword: *Piston ring, structural analysis, CFD.*

I. INTRODUCTION

The piston ring is one of the main components of an internal combustion engine. Its main purposes are to seal the combustion chamber of the engine, minimize the friction against the cylinder liner but also transfer heat from the piston to the cooled cylinder liner. Another important property of the piston ring is to evenly distribute oil along the cylinder liner in order to avoid engine seizure. One cylinder in a modern marine two-stroke diesel engine usually contains four to five piston rings referred to as the ring pack and for each of the piston rings there is a corresponding piston ring groove at the piston in which the piston ring is mounted. The top ring of the ring pack normally has a base material of higher grade cast iron and sometimes the ring is thicker and higher than the other piston rings in the ring pack. These design modifications are added because the top ring is working under higher thermal and mechanical load compared to the lower rings. When the engine is turned off the single piston ring is only affected by the contact surfaces against the cylinder liner and the piston ring groove. But when the engine is running the piston ring pack is also affected by gas pressures and temperature resulting from compression and combustion. The cylinder pressure acts on the upper part of the top piston ring and a fraction of the cylinder pressure acts below the top piston ring. Real working conditions can be idealized as shown in Fig. 1.

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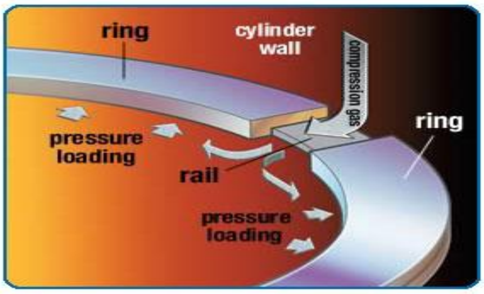

Fig. 1: Forces acting on Piston Ring

II. LITERATURE REVIEW

A. Main functions of piston rings

1) Sealing of combustion gases

The main task of compression rings is to prevent the passage of combustion gas between piston and cylinder wall into the crankcase as shown in Fig.2. For the majority of engines, this objective is achieved by two compression rings which together form a gas labyrinth. For design reasons, the tightness of piston ring sealing system in combustion engines is below 100%; as a result a small amount of blow-by gases will always pass by the piston rings in to the crankcase. This is however, a normal state which cannot be completely avoided due to the design. It is essential though, to prevent any excessive transfer of hot combustion gases past the piston and cylinder wall. Otherwise this would lead to power loss, an increase of heat in the components as well as a loss of lubricating effects. The service life and the function of the engine would consequently be impaired.

Fig. 2: Sealing of combustion gases

2) Scraping and distributing oil

Next to sealing the area between the crankcase and combustion chamber, the piston rings are also used to control the oil film. The oil is uniformly distributed on to the cylinder wall by the rings. Most excess oil is removed by oil control (3rd ring), although the combined scraper-compression rings (2nd ring) removes the oil. Fig. 3 shows scraper (wiper or 2nd ring) ring as well as oil ring (3rd ring).

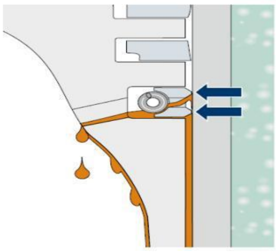

Fig. 3: Scraper and Oil Ring

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3) Heat dessipation

Temperature management for the piston is another essential task of the piston rings. The major portion of the head absorbed by the piston during the combustion process is dissipated by the piston rings to the cylinder surface. The compression rings, in particular, are significantly involved in heat dissipation. 50% of the combustion heat absorbed by the piston is already dissipated to the cylinder wall by the upper compression ring (depending on the engine type). Without this continuous heat dissipation by the rings, a piston seizure in the cylinder bore would occur within a few minutes or the piston even melt. From this perspective, it is evident the piston rings must always have proper contact to the cylinder wall. Whenever out-of-roundness is caused in the cylinder bore or if the piston rings are jammed in the ring groove (carbon fouling, dirt, deformation), it will only be matter of time until the piston suffers from overheating due to a lack of heat dissipation.

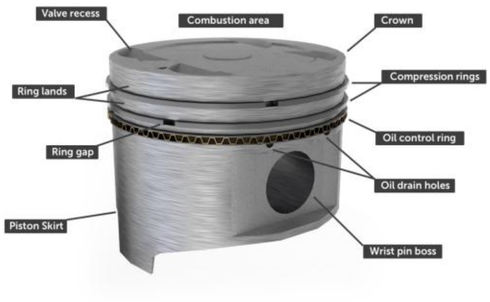

Fig. 4: Heat dissipation due to piston rings

B.Various analytical models present in Piston rings 1) Analytical Models

Based on literature review it is observed that traditionally piston ring studies are centered on two physics tribology and CFD. But there are few studies which includes structural design of piston rings. Following section reviews literature in the area of lubrication and flow.

2) Lubrication Models

Hawkers and Hardy [6] found that hydrodynamic lubrication (HL) prevailed throughout most of the engine cycle by friction measurements. They first proposed the evidence of hydrodynamic lubrication between a piston ring and a cylinder liner in 1936. Castleman [7] applied the concept of hydrodynamic lubrication to piston ring analysis. Eilon and Saunders [8] assumed a symmetric parabolic profile, and calculated the thickness of the oil film and the friction force of the ring. Furuhama [9] considered a ring profile consisting of a central flat region and two circular arcs at the two ends. The pressure acting on the piston ring in the radial direction is assumed to be composed of the pressure at the inner side of the ring and the piston ring elastic pressure.

3) Flow Models

The gas flow between the clearance is assumed to be a laminar flow due to the small Reynolds number (<1000) [10]. One-dimension Reynolds equation was used. The numerical approximation of this flow is similar to the hydrodynamics lubrication as previously described.

4) Structural Models

Many studies are based on experiments, tribology and CFD based as mentioned in earlier section. There is little understanding of structural approach in the design of piston rings. This work aims to study structural design of piston rings subjected to static loads as shown in Fig 1 using two methods: analytical methods and finite element method.

C. Findigs of the literature review

Currently, following methodologies are used in piston ring designs:

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1) Experimental

Various experiments have performed by researchers to design and test various loading conditions of piston rings.

2) Analytical

Various analytical formulations are available for design of piston rings based on physics of piston ring considered. Working conditions of piston ring are very demanding and requires understanding of multi-physics. Typically following three physics are involved in the design of piston rings:

- *Structural: Strength considerations in piston rings.*
- *Thermal: Considerations of Thermal expansion*
- *Fluid: Tribological conditions for better performance of the engine.*

Appropriate physics (single or coupled) is considered for

design of piston rings based on the objective.

3) Numerical

Various FEA based commercial tools are widely used such as ANSYS, Abaqus, Nastran, etc to validate or optimize the designs of various products. Use of FEA tools has reduced product development time. This is relatively new to the design and analysis of piston rings. In proposed work one of the FEA tool will be used to carry out design validations of one of the piston rings.

III. OBJECTIVE OF WORK

Piston rings have been in use for as long as combustion engines themselves. Despite this, ignorance or inadequate knowledge of piston rings is still frequently evident today. No other component is so critical when power loss and oil consumption are at stake. With no other component in the engine is the divide between expectations and utilized capital greater than when replacing piston rings. All too often, confidence in piston rings suffers due to the exaggerated demands made on them. As indicated in earlier, structural designs of piston rings are not studied adequately. Hence, the scope of this project involves following objectives:

A. *Selecting appropriate two-wheeler piston rings for carrying out this study.*

B. *Analytical (structural) design of piston rings using analytical formulations available in literature.*

C. *Finite Element Analysis of piston rings subjected to various loads acting on it.*

D. *Compare analytical and FE results.*

IV. CONCLUSION

1) Piston rings of reciprocating engines have several functions apart from sealing the gas pressure which affect performance of engine.

2) From lierature it appears that piston ring can be designed using experimental, analytical and numerical techniques.

3) Structural design of piston rings using FEA is not studied adequetly. Hence, design validation can be caried out using commercial FEA tools such as ANSYS, Abaqus, etc.

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