International Research Journal of Engineering and Management Studies (IRJEMS)
Volume: 03 Issue: 03 | March -2019 e-ISSN: 2395-0126

Introduction to Tribology and its Application in IC Engine: A Review

Santosh A. Rewaskar[1], Swapnil R. Umale[2]

[1]*Student, Department of Mechanical Engineering, Siddhivinayak Technical Campus Shegaon, Maharashtra, India.*
[2]*Asst. Professor & Head, Department of Mechanical Engineering, Siddhivinayak Technical Campus, Shegaon, Maharashtra, India.*

---***---

Abstract -*This study presents studies related to engine tribology in internal combustion engine. Friction loss is the main portion (48%) of the energy consumption developed in an engine. Lubricants are used to reduce the friction and wear and fuel consumption, increased power output of the engine, reduced oil consumption, a reduction in exhaust emissions in the engine. From the Analysis of the tribologist this means increasing specific loads, speeds and temperatures for the major frictional components of the engine, namely, the piston assembly, the valve train and the journal bearings, and lower viscosity engine oils with which to lubricate them. The literatures revealed that the most important parameter in the engine is lubricant, speed and load and with help of many different methods like blending the engine oil, remove the compression ring, additives are added to engine oil and analysis of piston ring assembly it can get the control on to the friction and wear and achieve almost all the objective that mention above.*

Key Words: Tribology1, friction2, wear3, lubrication4, Ic engine5.

1.INTRODUCTION

The motor car is one of the most common machines in use today, and it is no exaggeration to state that it is crucial to the economic success of all the developing and developed nations of the world and to the quality of life of their citizens. The motor car itself consists of thousands of component parts, many of which rely on the interaction of their surfaces to function. There are many hundreds of tribological components, from bearings, pistons, transmissions, clutches, gears, to wiper blades, tires, and electrical contacts. The application of tribological principles is essential for the reliability of the motor vehicle, and mass production of the motor car has led to enormous advances in the field of tribology. For example, many of the developments in lubrication and bearing surface technology have been driven by requirements for increased capacity and durability in the motor industry. For the purpose of classifying the tribological components, one Tribology comes from the Greek word, "tribos", it meaning is "rubbing" or "to rub" And from the suffix, "ology" means "the study of" Therefore, Tribology is the study of rubbing, or "the study of things that rub". [1, 2]

1.1 Tribology

Tribology is the science and technology of interacting surfaces in relative motion (and the practices related thereto), including the subject of friction, wear and lubrication. [3]

This includes the fields of:

• Friction, • Lubrication, • Wear,

1.2 Friction

When one solid body is slid over another so there is some resistance to the motion which is called friction. Considering friction as a nuisance, attempts are made to eliminate it or to diminish it to as small a value as possible. No doubt a considerable loss of power is caused by friction (e.g. about 20% in motor cars, 9% in airplane piston engine and (1 ½ -2) % in turbojet engines) but more important aspect is the damage that is done by friction – the wear or seizure of some vital parts of machines. This factor limits the design and shortens the effective working life of the machines. [1]

1.3 Lubrication

Lubrication is a substance inserted or introduced between the two contacting surfaces having relative motion, so as to reduce friction and wear. Any fluid having some amount of viscosity can be regarded as lubrication. It is evident that lubrication is required to minimize sliding friction in complete bearings. An additional function of the lubricant is to act as a protection for the accurately-ground and highly-polished surfaces of the balls, rollers and rings. If free moisture is allowed to contact the bearing elements, corrosion and pitting will follow and the bearing life will be considerably shortened. At the same time, a suitable lubricant should prevent the entry of external contaminating matter in the form of dirt or abrasive dust. [4]

1.4 Wear

Wear is the actual removal of surface material due to the frictional force between two mating surfaces. This can result in a change in component dimension which can lead to looseness and subsequent improper operation. The adhesion mechanism of friction enables us to understand the basic mechanism of metallic wear, when a junction shears during sliding it may shear in one or other of four ways. It produced by the processes of abrasion, adhesion, erosion, tribochemical reaction and metal fatigue. [1]

1.5 Tribological Properties

In characterization of tribology, the friction & the wear can expressed as a function of temperature, additive concentration, normal load or cycle time separately.

Although by plotting the stribeck curves for friction coefficient & wear scar diameter as a function of all rotation speed, viscosity & normal force. [1]

1.6 Tribosystem

Tribosystem consists of six elements. they are two contacting parts (base objects and opponent body), environment condition, intermediate materials, load & motion. Humidity, environmental temperature & pressure are the main environment condition. [1]

1.7 Objective

i) To study key concept of tribology and the various terms related to it.

ii) To study tribological properties in IC engine.

iii) To study the various tribological parameters on IC engine performance.

iv) To study the various ways to improve engine performance under friction &wear.

2. LITERATURE REVIEW

Ashkan Moosavian et al. (2016) in this paper's study the effects of piston scuffing fault on engine performance and vibrations are investigated in an internal combustion (IC) engine ran under a specific test procedure. Three body abrasive wear mechanism was employed to produce piston scuffing fault it caused the engine performance to reduce significantly. According to Continuous wavelet transform (CWT) analysis "dmey" wavelet, piston scuffing fault appeared in the scales of 7–14 (frequency band of 2.4–4.7 kHz) and more at the scale of 9 (frequency of 3.7 kHz) [5]

P.C. Mishra et al. (2014) in this paper's study the piston compression ring tribology and the theoretical and experimental works developed to analyze ring liner contact friction. Because of micro conjunction effect the friction is comparatively less in case of a rough liner 80 % Power Loss is in compression and power stroke together of total power loss in an engine cycle. Broad literature survey is carried out in the research area of piston compression ring to know about the simulation and experimental methods developed to study its performance. [6]

Dr. D. V. Bhatt et al. (2014) Measure the Piston Ring Assembly friction by the measuring the "Power consumption" under the different operating parameter like speed and lubricant on a motorized multi cylinder engine test rig. Initially the power consumption is reduces till 900 rpm but then it increases with increase in speed of the engine and lubricants properties varies with different manufacture. [7]

Santhalia and Kumar (2013) studied the effect of compression ring profile on friction force of internal combustion engine. Three different ring profiles were selected and analyzed of ring film thickness, the ring twist angles, the friction force and the friction coefficient using Secant method, for the compression ring. Hydrodynamic lubrication occurs for most part of the stroke except at the dead center where mixed lubrication regime was found due to reduced film thickness resulting in increased friction force [8]

Dr. D. V. Bhatt (2013) has used Sewing machine oil as blend oil in the Castrol GTX oil for oil analysis on the four ball tribotester. The coefficient of friction, wear scar diameter and frictional torque these parameters are measured with five different blending ratios two different loads and of oils. Coefficient of friction decreases and Wear scar diameter increases with the increases of the blending ratio of oil. [9]

P.C. Mishra (2013) has used a four stroke four-cylinder engine is modeled for lubrication performance. The detailed parameters related to engine friction and lubrication is computed numerically for the 1-3-4-2 engine firing order. To avoid friction and subsequent wear, the liner surface is textured with cross h pattern and the ring is coated with thermal and wear resistant coatings. [10]

Dr. D.V. Bhatt et al. (2013) added Titanium dioxide and P25 additives to re-refined base oil and the friction and wear characteristics were examined at a constant applied load and rate of reciprocation using reciprocating pin-on-disk apparatus. From this investigation it was found that the nanoTiO_2 particles addition to the base oil slightly reduced the coefficient of friction. [11]

N. Morris et al. (2012) compared an analytic solution to the average flow model is presented for this contact with a new analytical thermal model. Analysis carried out here corresponds to a typical cylinder of a V12 engine with an output power of 510 BHP. The combustion pressure variation piston sliding speed for engine speeds of 2000 and 6000 rpm respectively. These parameters are analyzed and compare between isothermal and thermal condition. [12]

Murat Kapsiz et al. (2011) In this paper's study The Taguchi design method with three process parameters sliding velocity, applied load and oil type was applied to optimize the reciprocating wear test for different commercial oil conditions of cylinder liner (CL)/piston. It was observed that the interactions between the control factors do not have significant influence on the weight loss and friction of the CL and PR pair. [13]

D. V. Bhatt (2011) in this paper's study paper reports a set of experiments were carried out on developed experimental setup at laboratory scale to measure PRA friction of multi cylinder 800 cc engine system indirectly by measurement of power consumption by Strip Method with variable frequency drive (VFD) is used to vary the engine speed. Frictional power loss contribution by individual piston ring varies under different speed. [14]

Mishra et al. (2008) studied the compression ring tribology at the vicinity of top dead center in Compression and power stroke transition. The aim is to attain full fluid film lubrication, thus reducing friction because of boundary interactions. [15]

George et al. (2007) predicted and compared their results with results from other semi-empirical models. In early studies, the squeeze film effect was neglected and a simplified hydrodynamic lubrication theory was applied to predict the oil film thickness. The model proposed by the authors considers that the complete ring pack can be reduced to a set of several compression rings and one twin-rail oil control ring. Each rail of the oil control ring is manipulated as a separate single ring. For the simulation of the oil film action between the piston ring and the cylinder liner, the one-dimensional Reynolds equation is used, considering sliding and squeeze ring motion. [16]

3. TRIBOLOGY IN IC ENGINE

To reduce friction and wear, the engine tribologist is required to achieve effective lubrication of all moving engine components, with minimum adverse impact on the environment. This task is particularly difficult given the wide range of operating conditions of load, speed, temperature, and chemical reactivity experienced in an engine. [17]

3.1 Importance of Engine Tribology

i) Improvements in the tribological performance of engines can yield:

ii) Reduced fuel consumption.

iii) Reduced oil consumption Increased engine power output.

iv) A reduction in harmful exhaust emissions.

v) Improved reliability, durability, and engine life.

vi) Reduced maintenance requirements and longer service intervals.

It is interesting to consider where the energy derived from combustion of the fuel is apportioned in an engine. In a published paper, Anderson (1991) showed the distribution of fuel energy for a medium size passenger car during an urban cycle. Only 12% of the available energy in the fuel is available to drive the wheels, with some 15% being dissipated as mechanical, mainly frictional, losses. Based on the fuel consumption data in Anderson's publication, a 10% reduction in mechanical losses would lead to a 1.5% reduction in fuel consumption.

The worldwide economic implications of this are startling in both resource and financial terms and the prospect for significant improvement in efficiency by modest reductions in friction is clear. Concerning energy consumption within the engine as shown in Fig 1 friction loss is the main portion (48%) of the energy consumption developed in an engine.

The acceleration resistance (35%) and the cruising resistance (17%) are the other portions. If one looks into the entire friction loss portion, engine friction loss is 41% and the transmission and gears are approximately 7%. Concerning engine friction loss only, sliding of the piston rings and piston skirt against the cylinder wall is undoubtedly the largest contribution to friction in the engine.

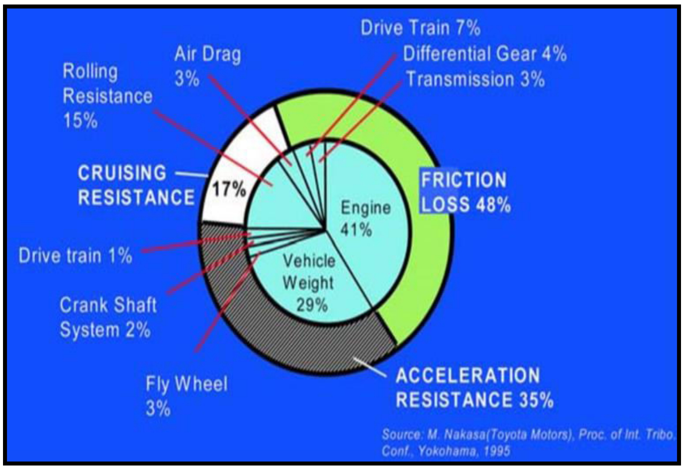

Fig -1 Energy Consumption Developed in an Engine.

4. ENGINE COMPONENT DESIGN AND ITS IMPACT ON FUEL ECONOMY AND WEAR CONTROL

Lubrication involves the smoothing of the rubbing process between contacting surfaces. A lubricant film between the surfaces would prevent direct solid- to-solid contact. The degree of solid-to-solid contact and the oil film thickness depend on the applied mechanical load, relative velocity, surface profiles, roughness, textures, as well as lubricant properties. There are different types of lubrication conditions or regimes, the fundamentals of which will be illustrated. There are many contacting surfaces in an engine system: in the piston assembly, valve-train components, and multiple bearing surfaces. The relative magnitudes of friction in these components will be examined.

4.1 Friction Analyses and Energy Distribution

While friction is a strong function of engine speed (rev/min), it varies less directly with engine load. Increasing the power output for a given sized engine at a given speed (viz. increasing the bmep) is a typical strategy of reducing friction as a percentage of engine work output. There are typical estimates of the relative magnitude of friction for common engine size and power output classes; however, these mostly empirically based estimates span a wide range and do not point to a simple distribution quantitatively.

A typical estimate of friction for a fired engine (diesel or SI), however, as a fraction of total fuel energy used is shown in Fig. in which mechanical friction is shown to take up roughly 4%–15% of the total fuel energy. This general estimate reflects typical in-use engine conditions, on the aggregate over various operating conditions, and does not apply to unique extreme conditions such as at idling and at very light loads where most of the fuel energy is consumed to overcome friction, with no net power output. Thermal efficiencies (work output/fuel used) of modern engines vary between 38%–50%, with 50% being a common development goal. Accordingly, mechanical friction is typically 10%–30% of engine power output, although it could be 100%, at idling, at the extreme.

The above estimate of mechanical friction is consistent with other estimates of total mechanical losses in an engine, which include pumping and accessory losses in addition to mechanical friction itself, at up to 40% of the gross (indicated) power output from the engine. Most of the mechanical losses, about 75%, are rubbing friction, although the relative pumping losses become more significant at lighter loads [18].

As engine power output from a given engine increases, friction becomes less as a percentage of power output. Therefore, mechanical efficiency typically increases with engine load. Friction could be a small fraction of engine power output, at 10% or less at high loads, and its relative importance increases at lighter loads, at 30% or more at part loads.

4.2 Breakdown of Friction by Engine Components.

Exclusions: Pumping losses result from the flow of intake and exhaust gases. Accessories include coolant and lubricant pump, fans, and other pneumatic systems that may be powered directly by the engine. The losses in these systems depend on parameters other than the traditional concept of lubrication or a lubricant. They comprise 20%–30% of total mechanical losses for accessories for heavy-duty diesels and 30%–50% for pumping loss for gasoline engines, depending on the operating speed and load. While important, these losses are not included in the current focused discussions on mechanical or rubbing friction. With the above exclusions, the three major subsystems of the engine contributing to mechanical friction are thus: (a) piston-ring-liner system, (b) crankshaft and bearings system, and (c) valvetrain system.

The exact distribution of the friction among these three groups depends on the particular engine, the component design details, and operating conditions. However, prevalent reported results show that the crankshaft system (main bearing and seals) contributes roughly 50%–100% higher friction than the valvetrain system, and the power cylinder friction approximately equals that from the valvetrain and bearing systems combined. Figure 2 shows a typical partitioning of the mechanical friction in the engine, among the three major component groups Friction and lubrication in these components groups will next be discussed. [19,20, 21]

4.3 The Piston-Assembly System

The piston assembly consists of the piston, piston rings, piston pin, connecting rod and bearings, as shown schematically in Fig. 3. There are three main friction and lubrication groups: (a) the piston-skirt surfaces sliding up and down the liner, (b) the ring-face surfaces of the ring pack likewise in reciprocating motion along the liner, and (c) the bearing surfaces in rotating motion in the wrist pin and connecting rods. The friction and lubrication in the bearings are similar to that in the crankshaft main bearings and thus will be discussed in the next section. Most of the piston-assembly friction comes from either (i) piston-skirt/ liner interaction, or (ii) ring-pack/liner interaction. Strictly speaking, there is also lubrication and friction as the rings slide radially against the inside surfaces of the ring grooves in which the rings reside. However, the ring-groove interactions are only intermittent and do not contribute significantly to energy losses, but rather to ring-grooves wear issues.

4.4 The piston-skirt-liner subsystem

Because of the kinematics of the connecting rod transmitting the piston reciprocating motion to rotating crank motion, side forces act on the piston laterally, causing what is termed secondary motion of the piston inside the cylinder.

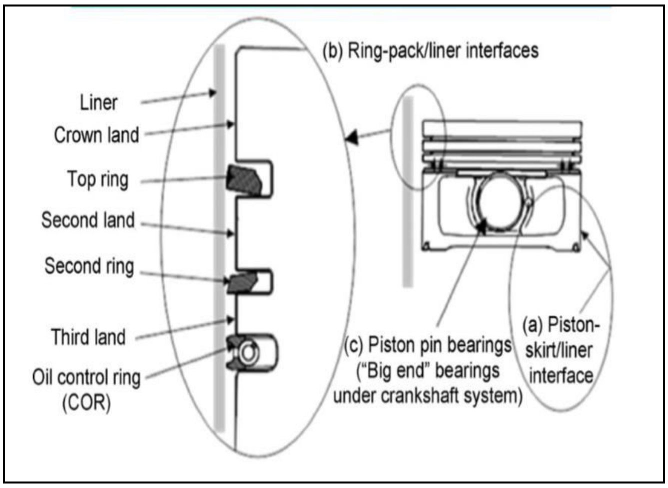

Fig-2 Piston Assembly System Showing (A) Piston-Skirt/Liner Subsystem, (B) Ring-Pack/Liner Subsystem, And (C) Piston-Pin/Piston Bearing Surfaces. Con-Rod "Big End" bearings under crankshaft Section.

4.5 Ring Dynamics and Gas Flows in the Ring Pack.

In addition to the radial forces of ring tension and gas pressure holding the rings against the liner, providing ring-liner seals, axial forces (gas pressure, inertia, and friction) also act on the rings, pressing the rings against the grooves surfaces, sealing the combustion gases from leaking around the rings in the grooves. The rings are carefully designed with a positive or negative twist angle (relative to the ring groove edges), as shown in Fig, to control the point of sealing and the pressure distribution around the ring. The axial forces and moments determine the ring's axial motion and its tilt in the ring groove. These axial forces include primarily the gas pressure forces acting on the flanks of the ring—intricately controlled by the designed twist (static twist)—balanced against the inertial force on the ring due to the reciprocating piston motion. The rings typically sit flat on the bottom groove flank about three-quarters of the time on the top groove flank about a quarter of the time, due to the higher gas pressure on the combustion chamber side.

There are two narrow time intervals, of a few crank angle degrees each, where a ring makes a transition from primarily one side of the groove towards the other. During ring transition, enhanced leakage of gases occurs. If the flow is towards the bottom towards the crankcase, there is increased blow-by. Reverse flow can also occur due to the inter ring pressure dynamics, when the cylinder pressure decreases faster than the reduction of inter-ring pressures. Oil consumption could increase when reverse flow occurs, either due to flow around the grooves or through the ring gaps.[22]

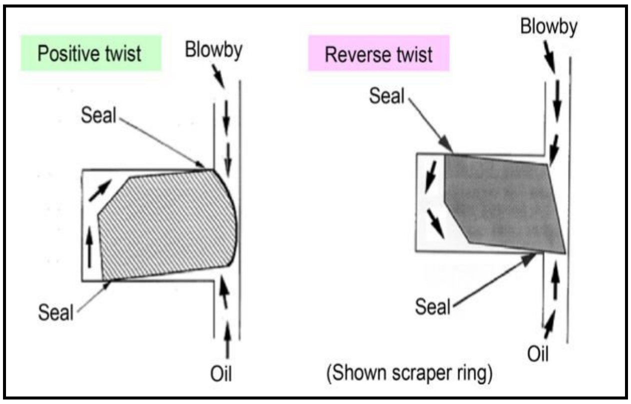

Fig-3 Schematic Illustrating Positive and Negative Static Ring Twists.

5. THE WAY TO IMPROVE PERFORMANCE

One of the way to improve the performance is discussed below, In addition to friction and wear control by the micro-design of engine component geometries and configurations, as described in the previous sections, friction and wear can also be controlled via the use of surface texturing or coatings.

5.1 Engine Friction Reduction by Surface Textures or Coatings

While coatings protect the surface from abrasive wear through the hardness of the material, surface texturing affects the friction and wear of the surfaces in intricate ways, and is the focus of the discussion in this section. Texturing has been recognized as a method for enhancing the tribological properties of sliding surfaces for many years. Early studies recognized the potential of micro-asperities to provide hydrodynamic lift during film lubrication, while more recently renewed interest in the role of surface texturing has yielded analytical and experimental results that reveal more detail about the mechanisms by which surface features influence lubrication and friction. Like large scale converging surfaces, micro-scale asperities can create an asymmetric oil pressure distribution that results in hydrodynamic lift.

In the case of mixed lubrication, this added lift can alter the balance between hydrodynamic and boundary lubrication, reducing the amount of asperity contact that takes place, and thus reducing both friction and wear. Also, even when contact does not occur, an increase in oil film thickness reduces shear within the oil, reducing hydrodynamic friction. Several studies, both analytical and experimental, have considered the effects of surface patterns in well-lubricated cases. Because they can assist in creating hydrodynamic pressure in the fluid film, textured surfaces have an effect on the lubrication regime of sliding surfaces. The lubrication regime in a series of experiments using a pin-on-disk test rig with unidirectional sliding, producing Stribeck- like curves for various textures and conditions. In general, adding surface dimples expanded the range of parameters under which hydrodynamic lubrication took place, extending the non-contact regime to low speeds and viscosities.

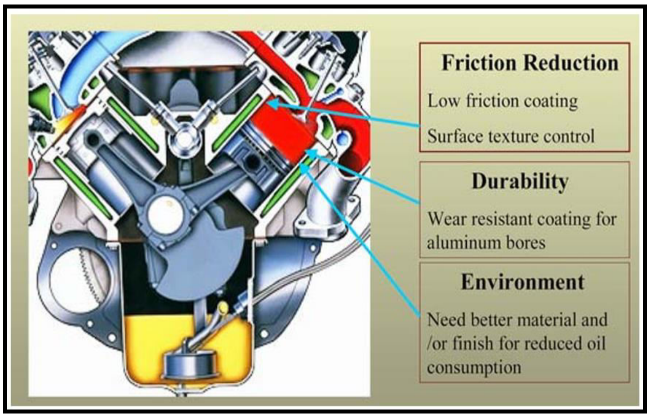

Fig-4 Research Opportunities for Improving Friction and Wear Reduction in An Engine Design.

Sadeghi and Wang have also demonstrated that texturing can reduce asperity contact, analytically showing that adding dimples in the end-stroke region of a reciprocating slider can reduce contact in this area. Several studies have also shown that friction can be reduced with the addition of surface dimples even when no contact occurs. Several analytical and experimental studies considering the effects of round dimples on sliding friction and load support. Analysis of "piston-ring like" cases showed that adding dimples to one surface could decrease friction in reciprocating sliding due purely to hydrodynamic friction reduction (asperity contact was not considered in the model). Reciprocating- slider testing also showed reduced friction for well- lubricated cases. Other results, though, suggested that the texturing could be harmful in poorly-lubricated situations.

6. CONCLUSION

In this manner, we have studied the key concept of the tribology and also the various terms related to it. During the study we briefly discussed about the tribological properties relating to the IC engine in particular. On forth, we observed the various tribological parameters affecting the engine performance predominantly. In the end, we gathered and proposed various ways which had proved to be beneficial in improving engine performance under the friction and wear.

REFERENCES

[1] http://shodhganga.inflibnet.ac.in/bitstream/10603/27627/7/07_chapter2.pdf, Aug 20 2018.

[2] http://www.slideshare.net , Aug 20 2018.

[3] D. R. Adams: "Tribological considerations in internal combustion engines" Wood head publishing Limited, 2010.

[4] Mukesh A. Bulsara, Dhananjay V. Bhatt, Kishore N. Mistry: "Measurement of oil film thickness between piston ring and liner using strain gauge Industrial Lubrication and Tribology"65/5 (2013) 297–304 q Emerald Group Publishing Limited.

[5] Ashkan Moosavia G. Najafi a, Barat Ghobadiana, Mostafa Mirsalimb, Seyed Mohammad Jafari b ,Peyman Sharghi "Piston scuffing fault and its identification in an IC engine by vibration analysis" Applied Acoustics 102 (2016) 40–48 2015 Elsevier Ltd

[6] P.C. Mishra: "A Review of Piston Compression Ring Tribology" Tribology in Industry Vol. 36, No. 3 (2014) 269280.

[7] Atul S. Shah and D. V. Bhatt: "Experimental Study to Measure Piston Ring Assembly Friction of Multi cylinder I.C. Engine (S.I.) on Motorized Engine Test Rig: A Case Study" H. C. Patel et al. (eds.), Proceedings of International Conference on Advances in Tribology and Engineering Systems, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1656-8_14, _ Springer India 2014

[8] A. Sonthalia a, C.R. Kumar: "The Effect of Compression Ring Profile on the Friction Force in an Internal Combustion Engine" © 2013 Published by Faculty of Engineering, Vol. 35, No. 1 (2013) 74-83.

[9] Dr. D. V. Bhatt. Dr. B. M. Sutaria, Dr. M. K. Bhatt, Mr. B. K. Sonigra: "ASTM Performance Tests to Study the Effect of Blend Oil with Based Oil Analysis for Automobile Engines" 4th International Conference on Mechanical, Production and Automobile Engineering (ICMPAE'2013) Oct. 6-7, 2013 Dubai (UAE0).

[10] P.C. Mishra: "Modeling for Friction of Four Stroke Four Cylinder In-Line Petrol Engine"© 2013 Published by Faculty of Engineering, Vol. 35, No. 3 (2013) 237-245.

[11] Sudeep Ingole, Archana Charanpahari, Amol Kakade, S. S. Umare, D.V. Bhatt, Jyoti Menghani: "Tribological behavior of nanoTiO2 as an additive in base oil" Wear 301 (2013) 776–785 2013 Elsevier B.V.

[12] N. Morris, R. Rahmani, H. Rahnejat, P. D. King, and B. Fitzsimons: "Tribology of piston compression ring conjunction under transient thermal mixed regime of lubrication" Tribology International 59 (2013) 248–258 & 2012 Elsevier Ltd.

[13] Murat Kapsiz, Mesut Durat, Ferit Ficici: "Friction and wear studies between cylinder liner and piston ring pair using Taguchi design method" Advances in Engineering Software 42 (2011) 595–603 2011 Elsevier Ltd.

[14] H R Mistry, D V Bhatt. "STUDY OF TRIBOLOGICAL PARAMETERS ON SI ENGINE – A CASE STUDY" International Journal of Advances in Engineering & Technology, July 2011

[15] P C Mishra, S Balakrishnan, and H Rahneja: "Tribology of compression ring-to-cylinder Contact at reversal" Proc. IMechE Vol. 222 Part J: J. Engineering Tribology JET410 © IMechE 2008.

[16] Livanos, G. A. and Kyrtatos, N. P. "Friction model of a marine diesel engine piston assembly". Tribology Intl, 2007.

[17] Dr. D. V. Bhatt. Dr. B. M. Sutaria, Dr. M. K. Bhatt, Mr. B. K. Sonigra: —ASTM Performance Tests to Study the Effect of Blend Oil with Based Oil Analysis for Automobile Engines. 4th International Conference on Mechanical, Production and Automobile Engineering (ICMPAE'2013) Oct. 6-7, 2013 Dubai (UAE0).

[18] Heywood, J. "Internal Combustion Engine Fundamentals". McGraw-Hill, New York, NY, 1988.

[19] Richardson D. "Review of power cylinder friction for diesel engines. J Eng Gas Turbine Power", Trans the ASME 122(4): 506–519 (2000).

[20] Taylor C M. "Engine Tribology". Amsterdam: Elsevier Science Publishers, 1993.

[21] James C J. "Analysis of parasitic losses in heavy duty diesel engines". M.S. Thesis. Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA, 2012.

[22] Wachtmeister G, Hubert A. "Rotation of a piston pin in the small connecting rod eye during engine operation". MTZ Worldwide 69(12): 52–57 (2008).