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Evaluation of Friction Force on Piston Ring of 4-Stroke Four Cylinder S.I. Engine: A Case Study

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Abstract – ABSTRACT
The piston ring assembly is very important part in internal combustion engine. The friction generated due to PRA has a major role in total frictional losses of the engine. The piston ring assembly is dominant sources of the engine friction force. This investigate attempts to evaluate the frictional force at the piston ring liner assembly by using different engine oil and at different crank angle. The experimental work was conducted on a four stroke 4- cylinder SI engine from speed range from 1550 rpm to 3800 rpm. It is seen that the maximum value of the frictional force is higher for the lubricant SAE30W which may cause of higher wear of the rings. The use of lubricant SAE15W in the given setup would cause less wear of piston rings due to reduce frictional forces.

KEY WORDS: Internal Combustion Engine, PRA , Piston , Friction, Cylinder.

1.INTRODUCTION

The purpose of the I.C. engine is the production of the mechanical power from the chemical energy contained in the fuel. In the internal combustion engine, as distinct from external combustion engine, this energy is released by burning or oxidizing the fuel inside the engine. The internal combustion engine is an engine in which the combustion of a fuel (normally a fossil fuel) occurs with an oxidizer (usually air) in a combustion chamber. In an internal combustion engine, the expansion of the high-temperature and -pressure gases produced by combustion applies direct force to some component of the engine, such as pistons, turbine blades, or a nozzle[14]. This force moves the piston over a distance, generating useful mechanical energy. The friction is an important consideration taken into account in the internal combustion engine operation.

2 Internal Combustion Engine

The internal combustion engine is an engine in which the combustion of a fuel (normally a fossil fuel) occurs with an oxidizer (usually air) in a combustion chamber. In an internal combustion engine, the expansion of the high-temperature and -pressure gases produced by combustion applies direct force to some component of the engine, such as pistons, turbine blades, or a nozzle. This force moves the component over a distance, generating useful mechanical energy. The term internal combustion engine usually refers to an engine in which combustion is intermittent, such as the more familiar four-stroke and two-stroke piston engines, along with variants, such as the six-stroke piston engine and the Wankel rotary engine[14].

1.2.1 Types of internal combustion engine [12]:

- **Two-stroke cycle**
- **Four-stroke cycle**
- **Six-stroke engine**
- **Diesel engine**
- **Atkinson cycle**

1.2.2 four-stroke cycle: As their name implies, four-stroke internal combustion engines have four basic steps that repeat with every two revolutions of the engine [12]

(1) Intake stroke (2) Compression stroke (3) Power stroke and (4) Exhaust stroke

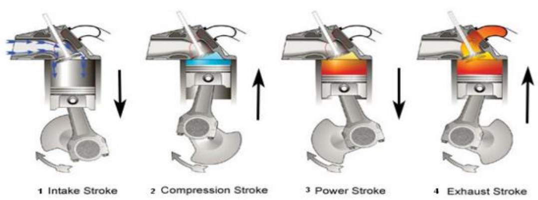


Fig No. 1.2 Schematic Diagram of 4 Stroke Petrol Engine [14]

4. Source of friction in internal combustion

The friction work is defines as difference between thwe work deliivered to the piston while the work fluid is contained within the cylinder(i.e., during the compression and expansion stroke) and the work delivered to the drive shaft, is expanded as follows:

- To draw the fresh mixture the intake system and into the cylinder , and to axpel the burn gases from the cylinder and out of the exhaust system . this is usually called the pumping work.
- To ovarcome the resistance to relative motion of all the moving parts of the engine . this includes the friction between the piston rings, piston skirt, and cylinder wall; friction in the wrist pin , big end crankshaft, and cam shaft bearing; friction in the valve mechanism ; friction in the gears, or pulley and belts, which drive the camshaft and engine accessries.
- To drive the engine accessories these can include: the fan, and the water pump, the oil pump, the generator, a secondory air pump for emmission control, apower steering pump and an air conditioner.

The absolute value of the total friction varies with ;load, and inrease as speed increases.the following terminology will be used in the engine friction .

Pumping work WP. The net work per cycle done by piston on the in cylinder gases during the inlet and exhaust strokes. WP is only defined for four stroke cycle engine.

Rubbing friction work Wrf . The net work per cycle dissipated in overcoming the friction due to relative motion of adjacent component within the engine .

Accessory work Wa. The work per cycle required to drive the engine accessories; e.g.,pumps, fan, generator. Normally , only those accessories essential to engine operation are included.

Total friction work Wtf . the total friction work is the sum of the these three components, i.e.

$$Wtf = WP + Wrf + Wa$$

Net indicated mean effective pressure, $imep_n$. the work delivered to the piston over the entire four stroke of the cycle per unit displaced volume.

From the above defination it follows that

imepg= imepn+ pmep

tfmep= pmep+ rfmep+amep

bmep= imepg-tfmep

bmep=imepn-rfmep-amep.

Two different defination of the indicated output are are in common use follow from different approaches to determining friction work or power.

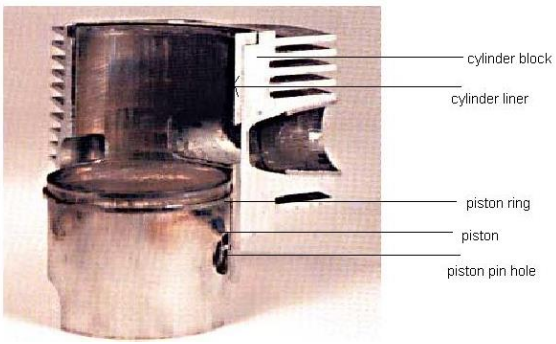


Fig No. 1.4 Piston Ring Friction Assembly.

1.4 The piston ring

The function of the piston ring is to form a seal for the high pressure gasses from the combustion chamber against leak into the crank-case.

1.41 Function of the piston ring[13]

In most modern medium, and large engine, the piston ring pack consists of three rings: two(upper) compression rings and one oil ring(fig.1.5).the ring perform following tasks.

The compression ring seal the combustion chamber from the oil sump during the compression and expansion stroke and by doing so, prevent the loss of pressure above the piston and this minimize blow-by.

Piston rings provide easy passage to heat flow from the piston crown to the cylinder walls. The piston is heated up when exposed to hot gases during the combustion stroke (convection and radiation). This heat is dissipated through piston rings.

Meter adequate lubricant to the cylinder surface to sustain high thrust and gas force loads at high surface speed and at the same time control oil consumption is acceptable limit.

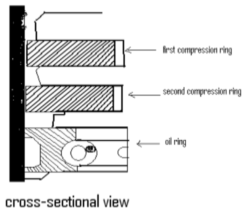


Fig No. 1.5 Cross Section View of the Piston Ring [10]

1.5 Piston ring material:-

The basic material for the piston ring is gray cast iron. The advantage of the gray cast iron is the relative low cast and compatibility with cast iron cylinder without need for the additional coating. Disadvantage is its brittleness, and with its sensitivity for breaking if the engine is subjected to heavy or continuous detonation.

TABLE NO 1.1 Piston ring materials and property

Material	Tensile strength(MPa)	Young's modulus(MPa)
Gray cast iron	350	85-115
KV1/G OE52 Ductile cast iron	1300	150
Steel	1150	230

A further increase in strength can be obtained by use ductile or nodular iron rings. Ductile iron

(KV1/GOE52) has been used for heavy-duty truck engines because its strength is roughly twice of that gray cast iron. This increase in strength is gained through the nodular shaped grains in its microstructure, in place of the sharp rectangular gray cast iron. In case of ductile iron, there two disadvantages. First increase in cost, the basic material costs more and it is more expensive to the machine. The other is that ductile iron is not as a compatible with cast iron cylinder wall as gray cast iron, and therefore needs a coating[13].

5.LITERATURE REVIEW

H.D.Desai et al.: found the kinematic value of piston at the alter crank angle and calculate the thrust force, bearing load. The results are computed form the computer developed for complete dynamic analysis of the engine. The gas force acts on the piston due to the combustion of the fuel and these force varies during the cycle of operation. The complete force analysis of the engine is simplified by a summation of static force and inertia force ignoring the friction force which makes the analysis linear.

F. S. SILVA :in his work investigate that engine piston are one of the most important part among all automotive or other industry field components. He concern only with the analysis of fatigue-damaged piston. Pistons from SI and CI engine, from automobile, motorcycle and trains will be analyzed. An analysis of both thermal fatigue and mechanical fatigue damaged is presented and analyzed in this work. He concluded that fatigue is not the responsible for biggest slice of damaged and pistons, it remains a problem on engine pistons and its solution remains a goal for piston manufacturers.

Paweł Lisiak a, Izabela Rojek b, Paweł Twardowski: The article describes a method of evaluating the reliability of groove turning for piston rings in combustion engines. Parameters representing the roughness of a machined surface, Ra and Rz, were selected for use in evaluation. At present, evaluation of surface roughness is performed manually by operators and recorded on measurement sheets. The authors studied a method for evaluation of the surface roughness parameters Ra and Rz using multi-layered perceptron with error back-propagation (MLP) and Kohonen neural networks. Many neural network models were developed, and the best of them were chosen on the basis of the effectiveness of measurement evaluation. Experiments were carried out on real data from a production company, obtained from several machine tools. In this way it becomes possible to assess machines in terms of the reliability evaluation of turning.

Ewa Rostek a, Maciej Babiak b, Emil Wróblewski : The purpose of the internal combustion engine lubrication system is to provide optimal conditions for the oil film formation in all friction couples, such as a piston-cylinder, piston rings-cylinder, main bearings, etc. The oil film is designed to minimize the wear of the elements while ensuring the smallest possible friction losses. Lack of continuity of the oil film, and thus boundary or mixed friction conditions, obviously have a negative effect on the friction losses. However, the continuous oil film, depending on the conditions of its formation, may be characterized by different values of friction losses. One of the factors that may affect the conditions of formation of the oil film is the value of oil pressure in the lubrication system. In the paper the results of researches on friction losses carried out on an engine test bench are presented. The study consisted of measuring the driving torque of the internal combustion engine by an electric machine which is the source of power for the internal combustion engine. The oil temperature, the oil pressure, which was generated by independent from the engine oil pump, and the rotational speed of the crankshaft were the variables during test stand measurement. The article analyzes the results and conclusions are drawn.

Y.H. Zweiri et al. [4] have presented the instantaneous friction components at any crank angle during the overall engine response. The main friction components are the piston assembly, the bearing, the valve train and the auxiliaries. The model includes analytically derived equation for the friction components of the ring assembly the bearing with mixed lubrication and the valve train. The engine friction model is validated with experiments on a two degree of freedom single cylinder diesel engine dynamic model using MATLAB5.2/SIMULINK2.2, software. The friction equations were based on the theoretical calculation for hydrodynamic and mixed lubrication.

Yean-Ren Jeng [7] has presented a one dimensional analysis for lubrication between the piston ring and cylinder wall. A fully flooded inlet condition and axisymmetric geometry were considered. The piston ring is treated as a reciprocating, dynamically loaded bearing with combine sliding and squeezed motion. A system of two non linear differential equation is used to model the lubrication including the Reynolds cavitations boundary condition. A numerical procedure is developed to obtain cyclic variation of film thickness friction force, power loss and oil flow across the ring. Results are presented for a typical automobile engine. It is shows that the analysis can be used to study the influence of ring design parameter in order to improve the design of the ring pack in reciprocating engine.

Objectives

The objective of the present work is to find the friction in PRA at various engine speeds and various crank angle position for two different lubricating oils.

DATA COLLECTION

Name	Description
Engine type	4-cylinder,4-stroke, petrol engine
Cylinder bore	70mm
Stroke :	75mm
Connecting rod length	150mm
Capacity	1089cc
C.R.	7.3:1
Cylinder head	Aluminum with valve seat insert, overhead valves
Cylinder block	Cast iron

Cooing pump Cooling water circulated by centrifugal
Lubrication oil filter Force lubrication with gear pump by pass
Fuel supply Fuel supplied by mechanical pump, down Draught carburetor with economy setting.
Ignition system Battery ignition system

5.3 Estimation of Indicated Power, Brake Power and Friction Loses using Morse Test. [13]

This is simple, quick and quite accurate test is used for determining the mechanical efficiency of the engine the equipment is required is only a water brake dynamometer and a tachometer, as used for brake power determination.

The Morse test consist of determining brake power of the engine at any particular speed, then cutting one cylinder at a time and measuring B.P. of the rest.

Now B.P.=WN/2000 kW (5.1)

Where

W= Load on the engine (kg) =6.5kg

N= Engine Speed (rpm)

I.P. = B.P. + Engine losses

1 Friction Force Calculation at Different Speed of the Engine.

Existing piston ring profile is shown in the figure no.5.7 and the hydrodynamic lubrication between the piston ring face and cylinder wall is assumed.

The value of the friction force for the two different lubricating oils at speed range from 3800rpm-1550rpmhave been presented in table no. 5.8 to 5.14.

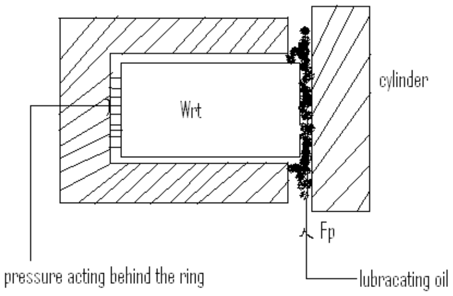


Fig No. 5.6 Piston ring profile

At speed 3800 rpm; Using Eq. (5.16)

TABLE NO. 5.8: Friction force value for SAE15W

Sr.	Crank angle θ (degree)	Piston velocity (m/s)	Fp (N)
1	0	0	0
2	30	9.02399	27.30
3	60	14.490	34.522
4	90	14.922	35.115
5	120	11.336	30.606
6	150	5.895	22.0712
7	180	0	0
8	210	-5.895	-27.30
9	240	-11.336	-34.522
10	270	-14.922	-35.115
11	300	-14.490	-30.606
12	330	-9.02390	-22.0712
13	360	0	0
14	390	9.02399	27.30
15	420	14.490	34.522
16	450	14.922	35.115
17	480	11.336	30.606
18	510	5.895	22.0712
19	540	0	0
20	570	-5.895	-27.30
21	600	-11.336	-34.522
22	630	-14.922	-35.115
23	660	-14.490	-30.606
24	690	-9.02390	-22.0712
25	720	0	0

TABLE NO. 5.9: Friction force value for SAE30W

Sr.	Crank angle θ°	Piston velocity m/s	Fp (N)
1	0	0	0
2	30	9.02399	31.462
3	60	14.490	39.774
4	90	14.922	40.458
5	120	11.336	35.263
6	150	5.895	25.429
7	180	0	0
8	210	-5.895	-31.462
9	240	-11.336	-39.774
10	270	-14.922	-40.458
11	300	-14.490	-35.263
12	330	-9.02390	-25.429
13	360	0	0
14	390	9.02399	0
15	420	14.490	31.462
16	450	14.922	39.774
17	480	11.336	40.458
18	510	5.895	35.263
19	540	0	25.429
20	570	-5.895	0
21	600	-11.336	-31.462
22	630	-14.922	-39.774
23	660	-14.490	-40.458
24	690	-9.02390	-35.263
25	720	0	-25.429

At speed 3000 rpm

TABLE NO. 5.10: Friction force value for SAE15W

Sr.	Crank angle θ°	Piston velocity m/s	Fp (N)
1	0	0	0
2	30	7.183	24.366
3	60	11.455	30.766
4	90	11.780	31.200
5	120	8.9482	27.1927
6	150	4.6549	19.1136
7	180	0	0
8	210	-4.6549	-24.366
9	240	-8.9482	-30.766
10	270	-11.780	-31.200
11	300	-11.455	-27.1927

12	330	-7.183	-19.1136
13	360	0	0
14	390	7.183	24.366
15	420	11.455	30.766
16	450	11.780	31.200
17	480	8.9482	27.1927
18	510	4.6549	19.1136
19	540	0	0
20	570	-4.6549	-24.366
21	600	-8.9482	-30.766
22	630	-11.780	-31.200
23	660	-11.455	-27.1927
24	690	-7.183	-19.1136
25	720	0	0

TABLE NO. 5.11: Friction force value for SAE30W

Sr.	Crank angle θ°	Piston velocity m/s	Fp (N)
1	0	0	0
2	30	7.183	28.070
3	60	11.455	35.448
4	90	11.780	36.250
5	120	8.9482	31.330
6	150	4.6549	22.952
7	180	0	0
8	210	-4.6549	-28.070
9	240	-809482	-35.448
10	270	-11.780	-36.250
11	300	-11.455	-31.330
12	330	-7.183	-22.952
13	360	0	0
14	390	7.183	28.070
15	420	11.455	35.448
16	450	11.780	36.250
17	480	8.9482	31.330
18	510	4.6549	22.952
19	540	0	0
20	570	-4.6549	-28.070
21	600	-809482	-35.448
22	630	-11.780	-36.250
23	660	-11.455	-31.330
24	690	-7.183	-22.952
25	720	0	0

At speed 2250 rpm

TABLE NO. 5.12: Friction force value for SAE15W

Sr.	Crank angle θ°	Piston velocity m/s	Fp (N)
1	0	0	0
2	30	5.344	21.014
3	60	8.5421	26.5714
4	90	8.8357	27.0212
5	120	6.710	23.5488
6	150	3.5992	17.2459
7	180	0	0
8	210	-3.5992	-21.014
9	240	-6.710	-26.5714
10	270	-8.8357	-27.0212
11	300	-8.5421	-23.5488
12	330	-5.344	-17.2459
13	360	0	0
14	390	5.344	21.014
15	420	8.5421	26.5714
16	450	8.8357	27.0212
17	480	6.710	23.5488
18	510	3.5992	17.2459
19	540	0	0
20	570	-3.5992	-21.014
21	600	-6.710	-26.5714
22	630	-8.8357	-27.0212
23	660	-8.5421	-23.5488
24	690	-5.344	-17.2459
25	720	0	0

TABLE NO. 5.13: Friction force value for SAE30W

Sr.	Crank angle θ°	Piston velocity m/s	Fp (N)
1	0	0	0
2	30	5.344	24.2119
3	60	8.5421	30.6144
4	90	8.8357	31.3270
5	120	6.710	27.0515
6	150	3.5992	19.8700
7	180	0	0
8	210	-3.5992	-24.2119
9	240	-6.710	-30.6144
10	270	-8.8357	-31.3270
11	300	-8.5421	-27.0515
12	330	-5.344	-19.8700
13	360	0	0
14	390	5.344	24.2119
15	420	8.5421	30.6144
16	450	8.8357	31.3270
17	480	6.710	27.0515
18	510	3.5992	19.8700
19	540	0	0
20	570	-3.5992	-24.2119
21	600	-6.710	-30.6144
22	630	-8.8357	-31.3270
23	660	-8.5421	-27.0515
24	690	-5.344	-19.8700
25	720	0	0

At speed 1550 rpm

TABLE NO. 5.14: Friction force for SAE15W

Sr.	Crank angle θ°	Piston velocity m/s	Fp (N)
1	0	0	0
2	30	3.6815	17.4425
3	60	5.9187	22.11559
4	90	6.0866	23.005
5	120	4.6297	19.5590
6	150	2.4042	14.095
7	180	0	0
8	210	-2.4042	-17.4425
9	240	-4.6297	-22.11559

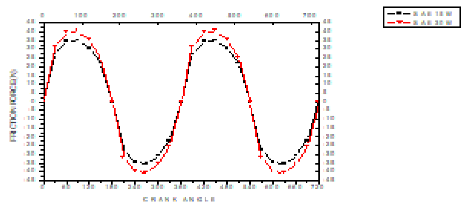
10	270	-6.0866	-23.005
11	300	-5.9187	-19.5590
12	330	-3.6815	-14.095
13	360	0	0
14	390	3.6815	17.4425
15	420	5.9187	22.11559
16	450	6.0866	23.005
17	480	4.6297	19.5590
18	510	2.4042	14.095
19	540	0	0
20	570	-2.4042	-17.4425
21	600	-4.6297	-22.11559
22	630	-6.0866	-23.005
23	660	-5.9187	-19.5590
24	690	-3.6815	-14.095
25	720	0	0

Result

S. NO.	Engine RPM	B.P. (kW)	I.P. (kW)	FP (kW)	P_I (MPa)	Total F.P. generated in the PRA system	% of total F.P. in the PRA of the F.P. of the
1	3800	11.4	23.9	12.4	0.3463	8.042	64.85
2	3000	9	17.71	8.71	0.32101	5.641	64.76
3	2250	6.75	12.47	5.72	0.31182	3.664	64.055
4	1550	4.65	9.08	4.43	0.3226	2.095	47.29

Friction force graph using different lubricating oil at different engine speed.

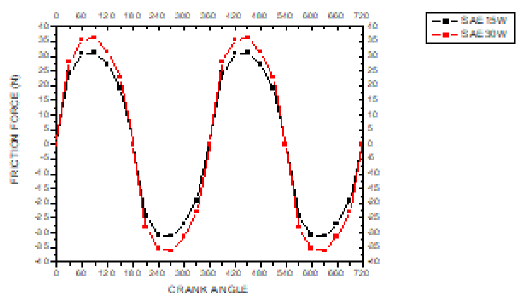
At 3800 rpm



Graph No. 5.2 Friction force vs. crank angle at 3800 rpm

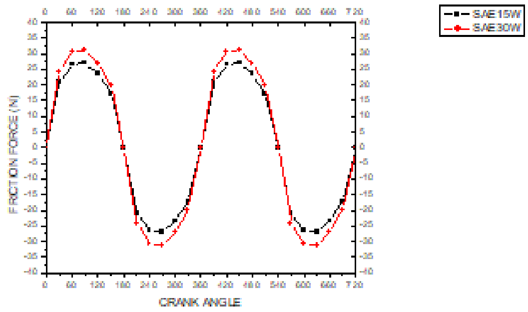
Friction force vs. crank angle at 3000 rpm

At 3000 rpm



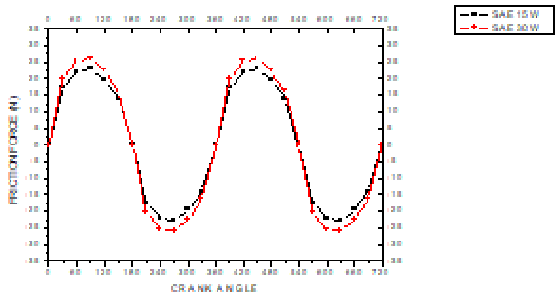
Graph No. 5.3 Friction force vs. crank angle at 3000 rpm

Speed at 2250 rpm



Graph No. 5.4 Friction force vs. crank angle at 2250 rpm

At 1550 rpm



Graph. No. 5.5 Friction force vs. crank angle at 1550 rpm

CONCLUSION

The experimental work was conducted on a four stroke 4- cylinder SI engine with an application of different lubricants (SAE15W and SAE30W) on given piston ring geometry from speed range 1550 rpm -3800 rpm. It was found that piston ring geometry plays an important role to reduce the PRA friction .

As engine speed increases the friction force also increases.

The power loss due to the friction at the interface of the piston ring and the cylinder liner is significant and is the major contribution to the total frictional power losses in I.C. engine the friction power loss at piston ring assembly seems to increase with engine speed.

It is observ that the maximum value of the frictional force is higher for the lubricant SAE30W which may cause of higher wear of the rings. The use of lubricant SAE15W in the given setup would cause less wear of piston rings due to reduce frictional forces.

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