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STUDY ON COMPONENT WISE FRICTIONAL POWER OF A SMALL SPARK IGNITED ENGINE

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Abstract. During the process of engine downsizing or modification knowledge of friction power is required to determine the actual power produced inside the combustion chamber of an engine. Though lubricating oils are used for avoiding direct contact of moving and rotating components, the friction is inevitable in engines. It is a very well known fact that an internal combustion engine consumes around 20 % of the indicated power. Efforts are being made by researchers around the world to reduce the energy consumed by friction by exploring various methods. But all these methods are inclined towards reduction in fuel consumption there by reducing the carbon footprint instead of component wise analysis for longer life and overall engine performance. In this current investigation, a detailed study is carried out on contribution by each and every component towards frictional power. This will shed light on analyzing frictional power in an enhanced way. The total engine friction is evaluated initially by fuelling the engine. To account for the total engine friction measured, component wise friction analysis is carried out by stripping down one component at a time and running the engine with the help of a prime mover. Frictional loss in piston and rings is expected to be around 40 to 50% of the total frictional power loss and the rest by valve train, about 20 to 30% and the remaining 20 to 30% is accounted by rest of the relatively moving components. In addition to the study mentioned above the effect of lubricating oil temperature and percentage of friction modifier in lubricating oil is also explored and presented.

Keywords: Frictional power, component friction.

Introduction. Ever since the internal combustion engine came into existence, researchers are trying to improve efficiency and decrease the operating cost by reducing the fuel consumption. The major factor influencing both the aforesaid terms is the mechanical losses, a major part of which is friction loss due to relative movement between rotating and reciprocating components. It is important to study the rubbing friction losses which directly influence engine output and specific fuel consumption. It is a well known fact that in SI engines only about 33% of the energy present in the fuel is converted to mechanical work. In spite of the knowledge of various losses, improving the efficiency of the engine always seems to be himalayan task. One reason for the inefficiency may due to the lack of awareness of the rubbing friction that is being contributed by each and every relative moving and rotating part. As the engine friction is considered as a whole, reduction may seem a daunting task. A detailed study of engine component friction will help in accurately evaluating the power consumption by various components which further help in carrying out analysis of the individual components. Tribology plays an important role in friction study for a strip down analysis [1]. A strip down analysis, or the break down analysis as it is called sometimes, was carried out in the current work to complete the frictional behaviour. More amount of time and money are being spent on the reduction of rubbing friction between piston rings, piston and liner. Today several new techniques are proposed by automotive industry reduce this friction. More information needs to be explored on the type and nature of this friction as it occupies a major part of the total rubbing friction of any engine. A floating liner method was employed in this study to carry out the in-depth analysis of the piston, ring and liner rubbing friction contribution. Similar studies by other researchers to find the friction between piston ring and liner using floating liner method is also reported in literature [2,3].

Lubricating oil plays an equally important role in reducing the engine friction. Again, as it is another vast area for research, lubricating oil contribution needs to be properly studied. Higher the temperature of the lubricating, lower the viscosity and hence low friction [4]. The piston and ring experiences boundary lubrication during lower speeds and shifts over to transition lubrication during medium speeds. During high speeds, hydrodynamic lubrication is experienced [5]. The role played by temperature, additives, properties of the oil, etc. contribute much in the research field.

1. EXPERIMENTAL SETUP

A 250 cc, single cylinder, SI engine was coupled to a DC motor cum generator on a test rig. Suitable ammeter and voltmeter were used for power measurements. The prime mover, a DC shunt motor, was chosen in order to keep the speed constant and precise without fluctuation. A simple sketch shown in Fig. 1 describes the experimental set up of the test rig onto which the engine and motor are being mounted by using bolts and nuts and are coupled to each other by a 6-hole spider. The reason behind using a 6-hole spider flange coupling is that, being made of tough rubber and steel, it reduces the amount of vibrations transferred between the motor and the engine. A separately excited DC Shunt Motor is used as the prime mover to motor the engine. A DC motor is used because it has wide speed range above and below the rated speed which is not the case in AC motors. A Shunt motor keeps the speed precise, again a drawback that is found in AC motors. The motor is powered from AC supply through suitable rectifiers, which convert the AC supply into DC power. A Ward-Leonard type of connection is used in which an Auto Transformer aids in varying the input voltage in order to regulate the prime mover speed from zero to speeds above rated speed. An electrical circuit diagram shown in Fig. 2 represents the connections given in the installation

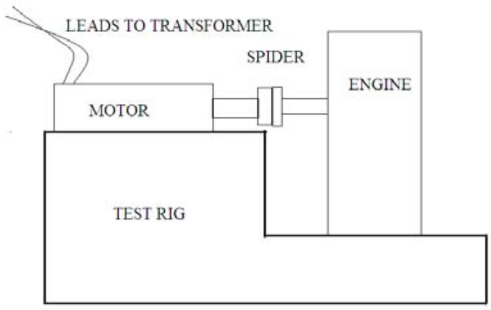


Fig. 1 – A simple sketch of the experimental setup depicting the prime mover (DC Shunt Motor) and the Engine on the test rig.

Table I – Engine Specification

Make	: Greaves MK-25
4-Stroke side valve, single cylinder.	
Engine capacity	: 256cc
Bore	: 70mm
Stroke	: 66.7mm
Maximum power	: 2.5 kW @
Maximum torque	: 14 Nm @
Compression ratio	: 4.67
Cooling system	: Forced
Lubrication	: Splash type.

The study is divided into three major sub groups or tests. The major tests that were carried out were 1) Strip down test (break down test), 2) Floating liner test and 3) Overall engine friction study with varying lubricating oil temperature and varying percentage of friction modifier in lubricating oil . To carryout third major sub group or test, four types of lubricating oils were used and they are Sample 1 which is base mineral oil derived from petroleum fractions. Sample 2 contains 97.5% base oil and 2.5 % friction modifier (molybdenum disulfide), Sample 3 contains 95% base oil and 5 % friction modifier (molybdenum disulfide), Sample 4 contains contains 92.5% base oil and 7.5 % friction modifier (molybdenum disulfide). The results of effect of lubricating oil temperature on engine friction with respect to sample 2 are presented here.

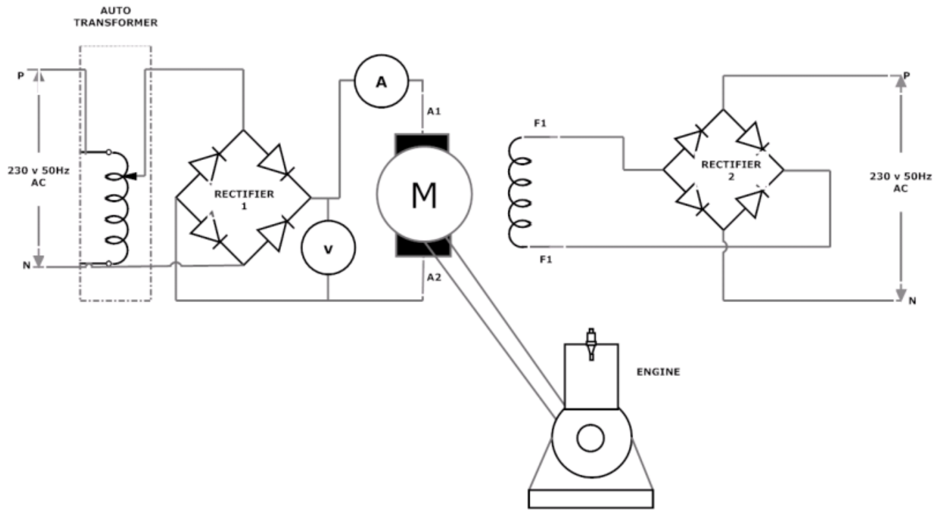


Fig. 2 – A simple sketch of the circuit representing the DC Shunt Motor (prime mover) electrical connections (Ward-Leonard type of connection)

Strip Down Test. Strip-down test or the break down test is used to measure the contribution of each and every individual component for total engine friction. To break down the total friction losses encountered in the engine, a thorough strip down analysis was carried out in which the engine run by the prime mover was stripped down one component at a time in the following order:

1. Top piston ring
2. Middle piston ring
3. Bottom piston ring
4. Piston, rings and connecting rod assembly
5. Valves and springs
6. Cam shaft
7. Flywheel

Strip down test is one in which the engine is motored by using a prime mover and the power consumed by the electric motor is noted down. This power consumed directly corresponds to the frictional power of the engine after subtracting the motor losses. In the next step, one component is removed (say top piston ring) as per the schedule provided above (from 1 to 7) and power consumption is estimated. Now after dismantling and re-assembling, the engine (after removing the top piston ring), it is motored by the prime mover and the power consumed by it is noted down, which, with a little consideration will reveal that it will obviously be lesser than the initial reading. This difference in the power consumption between the above said readings yields the power consumed by the top piston ring. The test is taken at various speeds ranging from 0 to 2000rpm. In the next step the first piston ring is assembled back and the middle piston ring is removed and the engine is assembled again. The same procedure is followed to find the friction power of all the components. The last step in this strip down analysis is the removal of flywheel. The engine (minus piston & connecting rod assembly, valve train and flywheel) is re-assembled onto the test rig and coupled to the prime mover, motored at various speeds and the power consumed is noted down, which will be lower than the previous reading(engine without piston & connecting rod assembly and valve train). This difference in power consumption will give the contribution of the flywheel.

All the while, during these experiments, the cylinder head was removed to exclude any pumping effect onto the other readings. Now, the cylinder head and all the other components are put and the engine once again assembled, mounted on the test rig and coupled the same prime mover. Now the engine is again motored at various speeds similar to the above experiments and the power consumed by the prime mover is noted down. A little consideration will reveal that this power is higher than the power consumed by the engine with all components intact but without cylinder head. This difference in power will give the contribution of the pumping losses. The total engine friction is the sum of the rubbing friction and the pumping losses.

Floating Liner Test. This method is useful in determining the piston and ring friction. It is helpful in specifically targeting the rubbing friction between the piston rings, piston skirt and the cylinder liner. A simplified floating liner setup was designed and fabricated in the laboratory for this test. In this experiment, the cylinder liner is designed in such a way that it has no restrictions for movement by the cylinder bolts. The liner is constrained in such a way that it can move only in the vertical direction (i.e. it can move only along its own axis-either upward or downward). All other degrees of freedom are arrested. The mounting bolts of the cylinder liner are loosened and the liner is set free. Instead the cylinder liner is arrested by the supporting stand which, as already mentioned, allows the liner to move in vertical direction alone. A Kistler make piezo-electric force sensor is used in between the liner and the supporting stand. As the piston reciprocates, it exerts a force on the cylinder liner vertically and this force is measured by using the force sensor.

A little consideration will show that, when the piston is in upward stroke, the rubbing friction between the piston rings and piston skirt tend to impart a force by which the cylinder liner will try to travel along with the piston on its way up towards Top Dead Centre (TDC). But the force sensor restricts this upward movement of the liner and converts the movement (which, in microns, actually takes place and cannot be seen by naked eye) into voltage signals and then to force in Newtons. Thus the rubbing force or the frictional force exerted by the piston rings and piston skirt on the cylinder liner is actually measured during the inward and the outward stroke of the piston. A Kistler crank angle encoder is used to measure the crank angle. The Frictional force versus crank angle graphs are generated by the help of a Agilant Digital Oscilloscope and dedicated computer (which converts the Voltage versus time graphs displayed in oscilloscope into Frictional force versus crank angle graphs in excel sheet using NI data card and LabView software). Fig. 3 represents the floating liner arrangement designed and fabricated for this study.

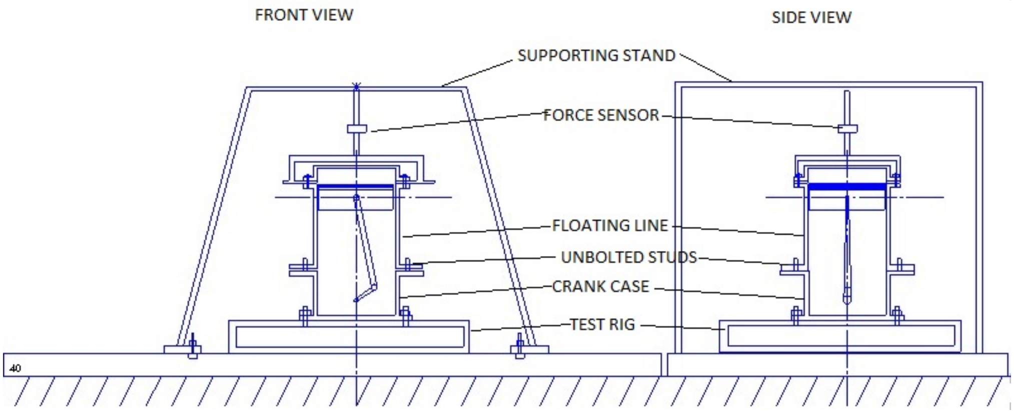


Fig. 3 - A simple sketch of the floating liner setup.

Result and discussion. The frictional power contribution found during the first stage of testing, using the strip down analysis method is given in the form of friction pie charts as shown in Figures 4a to 4h. These figures represent the amount of friction power contribution of each and every individual component for particular lubricating oil at a particular temperature. Figure 5 depicts the consolidated friction pie chart at 2000 rpm for the strip down analysis. This figure clearly shows the piston rings contribution as about one fourth of the rubbing friction, flywheel contributes more than one fourth of the rubbing friction and connecting rod assembly (which includes big end, small end and piston skirt friction) contributes less that about half of the total rubbing friction. All the figures represents rubbing friction alone.

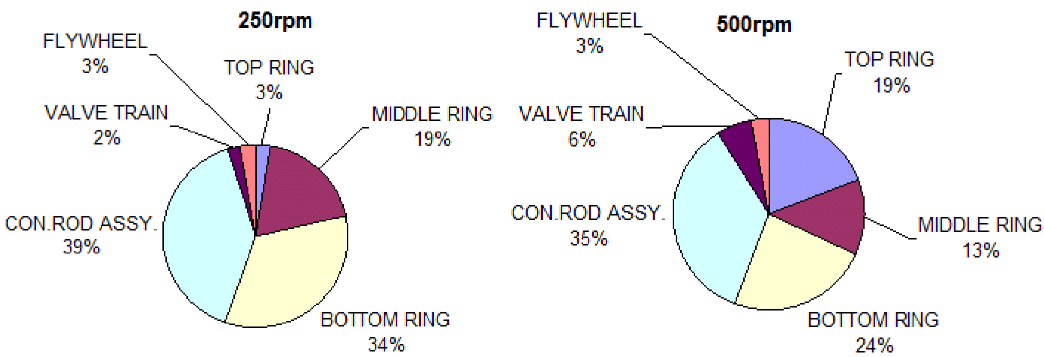
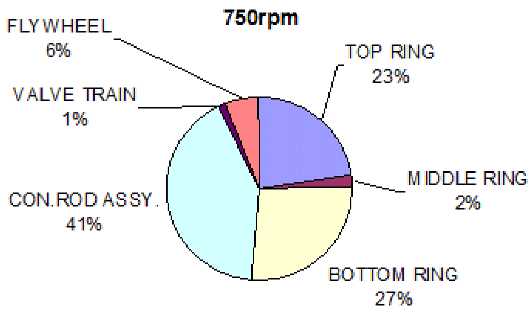


Fig. 4a& 4b – Friction pie at 250 and 500 rpm.



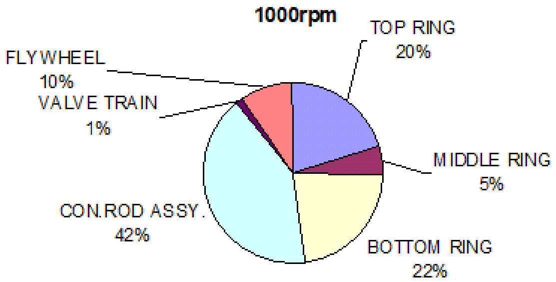
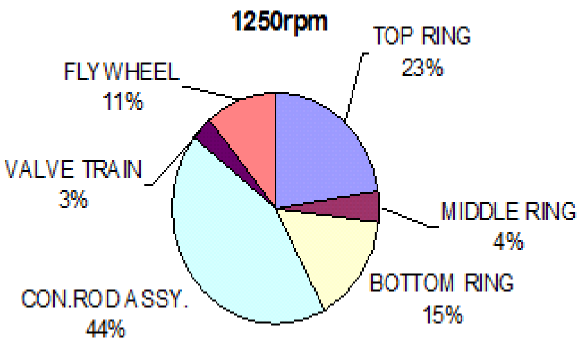


Fig. 4c& 4d – Friction pie at 750 and 1000 rpm.



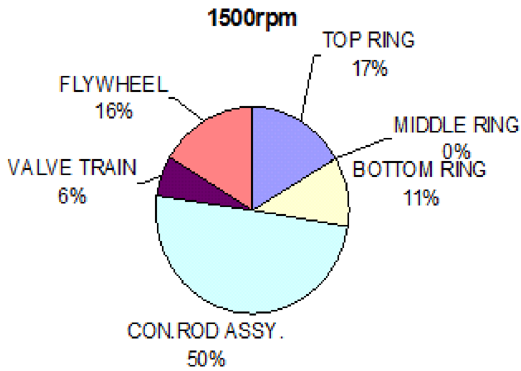
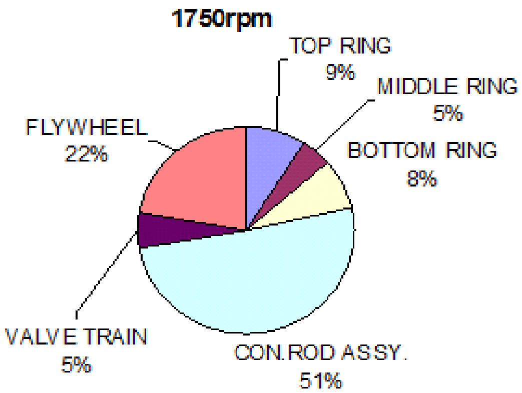


Fig. 4e& 4f – Friction pie at 1250 and 1500 rpm.



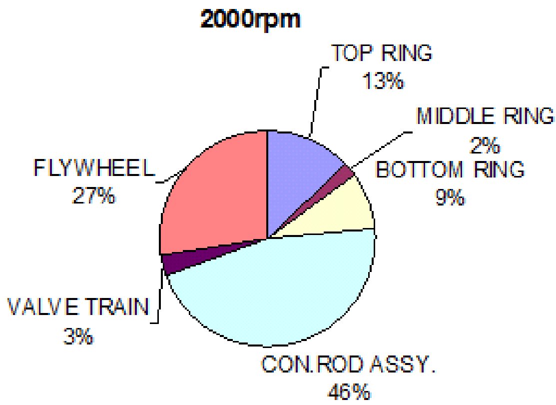


Fig. 4g& 4h – Friction pie at 1750 and 2000 rpm.

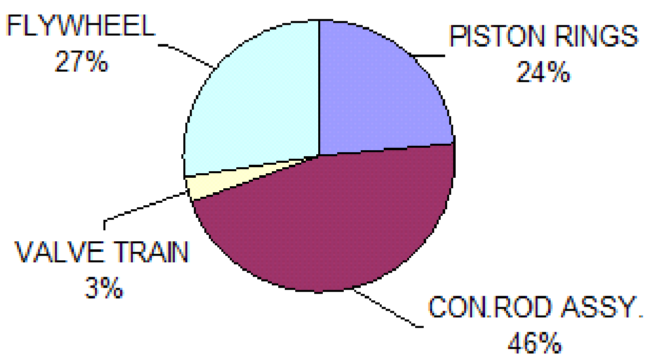


Fig. 5 – Consolidated Friction pie at 2000 rpm.

The contribution of flywheel in terms of Watts and percentage of rubbing friction is given in Figures 6 and 7 respectively. At low speeds the contribution from flywheel was almost negligible. As the speed increased, the contribution of the flywheel was palpable. The flywheel contributed 112.3Watts at 2000 rpm which was about 27% of the total rubbing friction contribution. The trend shows that the contribution of friction continuously increases as the speed goes further up. This is purely due to the weight of the flywheel and centrifugal force. The frictional force tends to increase square times the speed and thereby the friction power follows this trend at the same rate. This force tends to act at the journal bearing loading it unequally thereby trying to rupture the oil film thickness as a result promoting metal to metal contact between the shaft and the bearing. Higher the weight of the flywheel, more the centrifugal force and hence more chance of metal to metal contact at the journal bearing and as a result higher friction. Even though the flywheel stores energy when the supply to it is higher, it does not always return back the same amount of energy during demands (suction, compression and exhaust strokes). The efficiency of the flywheel may well depend on this calculation. High speed engines tend to have eminent friction which may be due to a heavy flywheel contributing too much to the rubbing friction at higher rpms. The flywheel that was used for the current work weighed about 3.5kgs. Any minor attempt to lower the weight of the flywheel may reap rich rewards as the friction is reduced drastically. The contribution is more eminent in case of high speed engines.

There was a certain amount of hysteresis which is though very negligible but worth mentioning because of the trend that it followed. Figure 8 depicts the hysteresis trend. The amount of friction is more when the piston is in accelerating mode at a particular rpm and the amount of friction comparatively is lower when the piston is in decelerating mode for the same rpm. This difference, though very minimal-about 40Watts or even less, is coined as hysteresis. The reason for the reduction in friction during decelerating mode may be due to better lubricating conditions during higher speeds (more number of splashes and better film coating at the liner). Thus when the piston speed is reduced (engine rpm reduces) better lubricating conditions co-exist for a certain period of time thus resulting in slightly lesser amount of friction. It is also worth mentioning that the hysteresis evens out, i.e. the difference in friction power consumption becomes zero or approaches values closer to zero, when the engine is run and maintained a particular rpm for few minutes both during accelerating and decelerating mode.

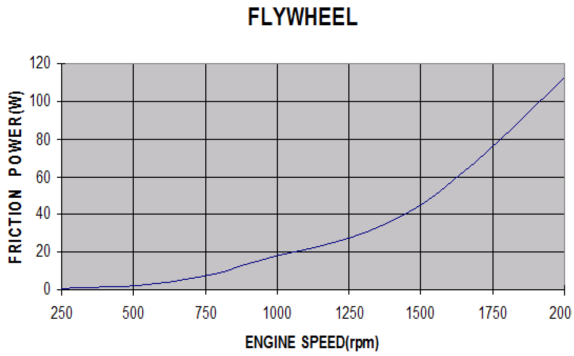


Fig. 6 – Contribution of flywheel to frictional power ranging from 0 to 2000 rpm

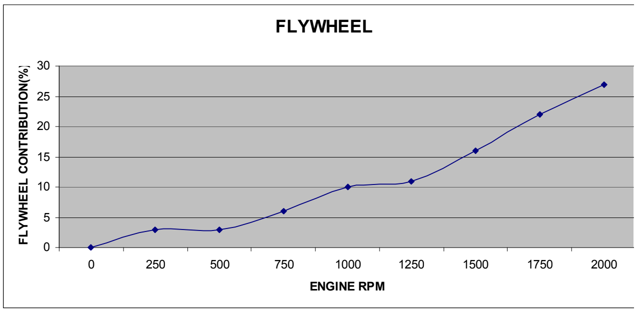


Fig. 7 – Contribution of flywheel to frictional power in terms of percentage of rubbing friction ranging from 0 to 2000 rpm.

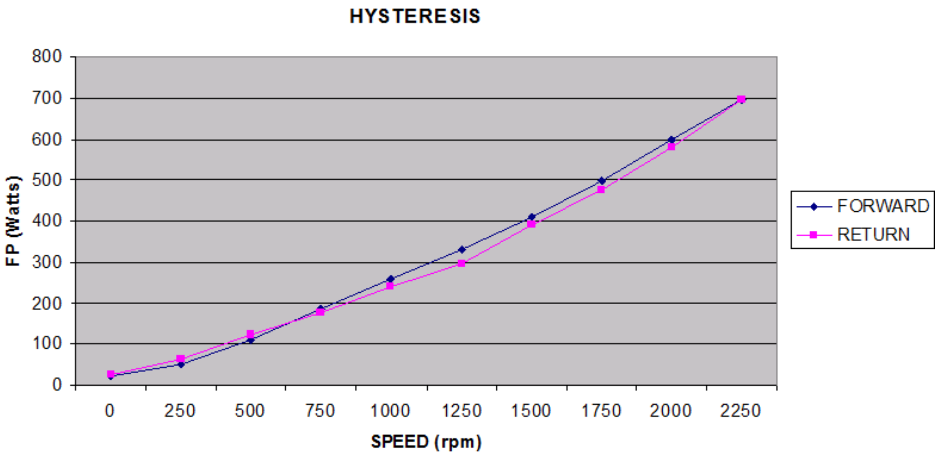


Fig. 8 - Contribution of engine friction hysteresis

Temperature of the lubricating oil (with sample 2 oil) plays less prominent role in the friction contribution as is evident in Figure 9. Although a slight amount of reduction in friction can be expected by maintaining the temperature of the lubricating oil at a particular value. This temperature may vary from oil to oil and also from engine to engine. It depends also on the clearance between the piston skirt and the liner, ring tangential load, etc. In the current work, the engine tended to produce less friction when the lubricating oil was maintained around 50 degree Celsius. Different temperatures like 35 and 75 degree Celsius were tried but it resulted in a slightly higher amount of friction to the tune of 30 Watts and less. The reason for increase in friction at lower temperatures (say around 35 degree Celsius) may be due to the viscous property of the lubricating oil at lower temperature. Vice versa is the condition for higher temperatures (say around 75 degree Celsius) where the oil loses its viscous property and thereby tends to breakdown quickly without maintaining the required oil film between the liner and the piston ring and skirt.

Figure 10 depicts the contribution of connecting rod assembly which includes the small end, the big end of the connecting rod and the piston skirt friction. The contribution of connecting rod assembly to the rubbing friction increases as the speed of the engine increases. This may be due to higher amount of slap of the piston skirt onto the liner. Also the increase in speed of the engine increases the swivelling speed of the small end of the connecting rod and higher rotational speed between the crank and the big end of the connecting rod. The contribution of the connecting rod assembly tends to increase at a slower pace compared to the flywheel contribution. As can be seen from the figure 10, the contribution of connecting rod assembly starts from about 35% of the total rubbing friction and contributes about slightly higher than 50% at about 2000 rpm. The trend shows that the contribution increases and evens out after certain rpm or the increase is very paltry as the speed increases drastically.

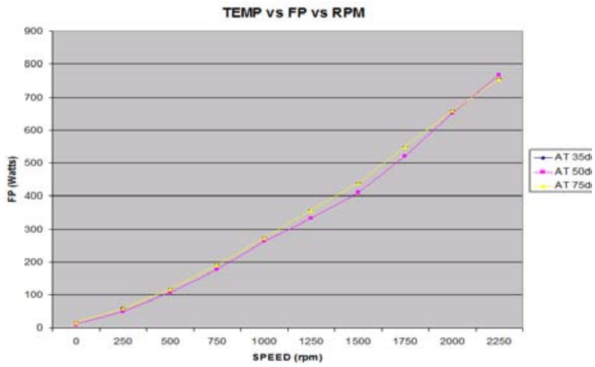


Fig. 9 – Temperature of lubricating oil and its friction contribution.

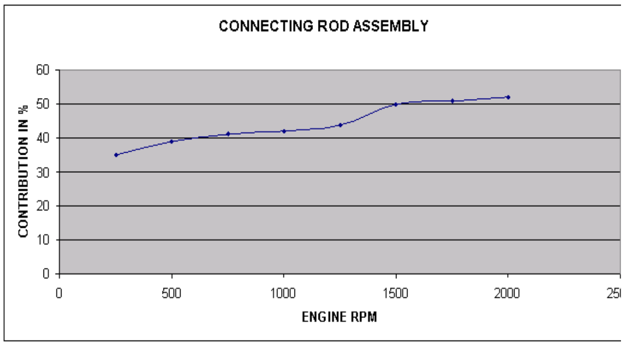


Fig.10 - Contribution of connecting rod assembly to engine rubbing friction

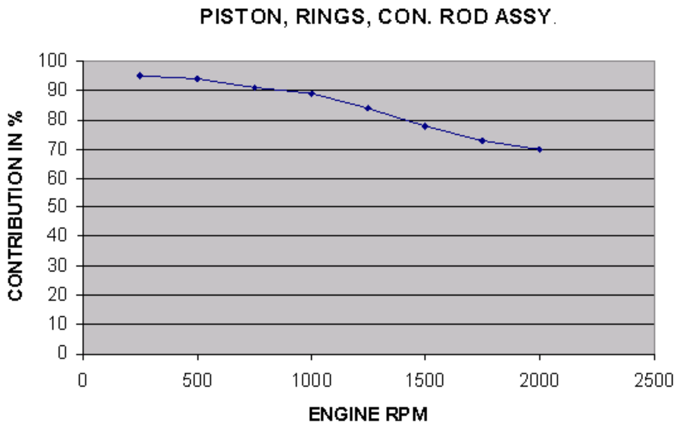


Fig. 11 - Contribution of piston, rings and connecting rod assembly to engine rubbing friction.

Figure 11 depicts the combined contribution of piston and connecting rod assembly which include piston rings, piston skirt, big end and small end of the connecting rod. The trend shows a ramp down in friction contribution though steeper compared to the ascent achieved by the connecting rod assembly contribution. The contribution of the piston and connecting rod assembly starts from about 95% of the rubbing friction and gradually decreases as the speed increases steadily. The trend shows that there might further decline in the contribution as the engine gains speed above 2000 rpm. The trend shows a decline mainly due to the percentage of contribution taken away by the flywheel. As the engine speed increases, flywheel contributes more and more to the rubbing friction and thereby creating the decline in piston and connecting rod assembly contribution.

The contribution of piston ring pack alone is specified in Figure 12. The declining trend is more evident in this figure as the engine gains speed. The piston ring pack, which includes the first-top, second-middle and third-bottom piston ring, contributes about 56% percentage at 250rpm and tends to contribute as less as 21% at 2000 rpm. The trend shows that further increase in engine speed will tend to reduce the piston ring pack and liner rubbing friction. Better splashing by the scoop (the engine employs splash lubrication system) and a pronounced oil film thickness at higher engine speeds tends to reduce the rubbing friction between piston ring and liner. Although the friction power consumed increases as the speed increases, the contribution of this to the rubbing friction tends to provide a declining trend. Prominence of flywheel contribution and better lubrication oil film thickness at the cylinder liner may be the reasons.

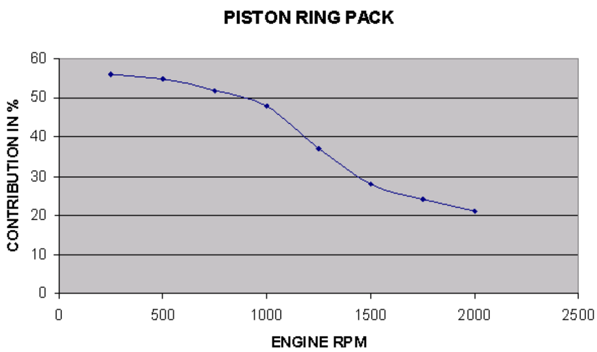


Fig. 12 - Contribution of piston ring pack towards rubbing friction.

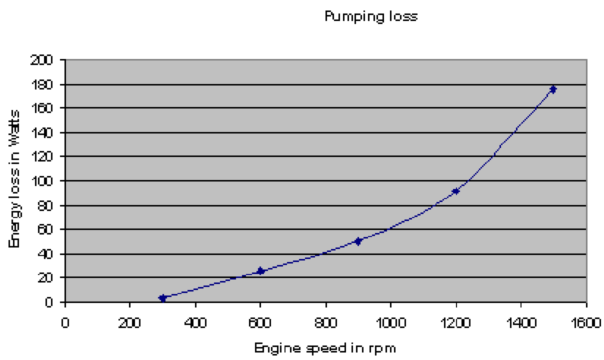


Fig. 13 - Contribution of energy loss due to pumping.

Figure 13 depicts the contribution of energy loss due to pumping action. The energy lost due to pumping involves the sucking of air into the cylinder and the expulsion of exhaust (air in the case of motoring tests). Some amount of energy needs to be imparted to achieve charge/ air motion and this account for the pumping losses. The pumping losses trend tends to follow an ever increasing contribution to the amount of energy loss, thus indicating the drastic increase of pumping losses during marginal increase of engine speed. Volumetric efficiency is a factor that needs to be considered for a better understanding of the graph depicted in figure 13. This represents that more amount of energy is spent to suck in fresh charge and expel out burnt exhaust during high speed of the engine. Vice versa for volumetric efficiency as it tends to decrease as the speed increases.

The typical output captured using digital oscilloscope (CRO) is transferred to PC and the values are converted to reverent output. The fluctuating line represents the frictional force due to the rubbing friction between piston, rings and the liner. The other continuous and occasional peak line represents the crank angle. The peaks represent the Top Dead Centre (TDC). All the above figures are taken by carrying out strip down test. The figure 15 is a product of floating liner method. The same procedure of floating liner method is used and the engine is run at different speeds. At each and every speed the friction force readings are noted down. The speeds in which the readings were taken ranged from 0 rpm to 2000 rpm.

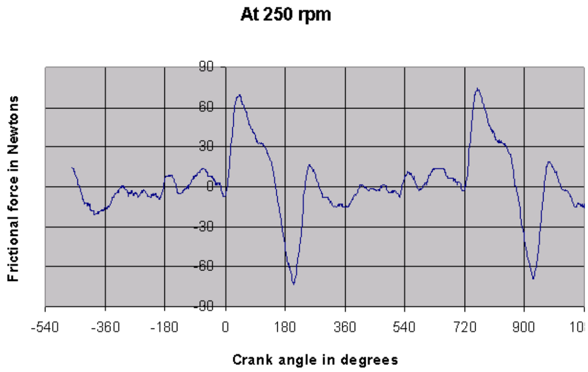


Fig. 14 – A typical example of the graph generated by the computer taking inputs from the CRO.

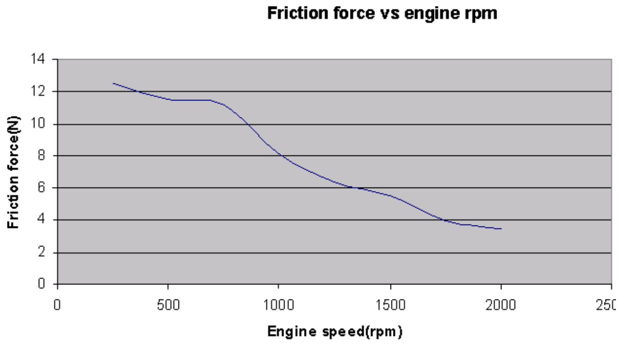


Fig. 15 – The trend followed by the friction force exerted on the cylinder liner vertically.

The amount of frictional force decreases with increase in engine speed as can be noticed in the figure 16. It depicts how the average friction force over the entire cycle exerted by the piston, ring pack on the cylinder liner decreases sharply in line with the strip down analysis findings shown in figure 12. The reasons for this as mentioned in the earlier paragraphs may be improved splashing of the lubricating oil leading to better maintenance of oil film thickness.

The effect of percentage of friction modifier in lubricating oils is presented in figure 16. The figure clearly shows that the friction modifier has significant effect on engine friction at lower engine speeds. The base lubricating oil has slightly higher friction power compared to samples 2, 3 and 4 at the same time friction modifier higher than 2.5 % has negligible effect on friction reduction. .

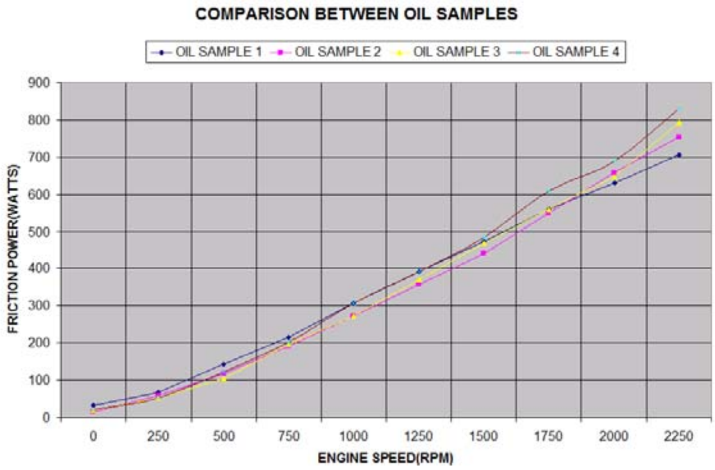


Fig. 16 – Graph indicating frictional power consumption for different oil samples.

Conclusion. From the graphs it is decipherable that piston and connecting rod assembly contributes to about 70% of the rubbing friction. Since the engine is a single cylinder engine and therefore many auxiliary equipments do not find place. Therefore the total friction does not carry the power consumed by the auxiliary equipments. When pumping losses are taken into account, they contribute a major chunk to the total friction. At higher speeds, pumping friction tends to contribute more to the energy loss. Also, the valve train contributes much lesser than anticipated. At speeds of about 2000 rpm and above, the valve train contribution for the rubbing friction was very much less than 5%. This data includes both inlet and exhaust valve mechanisms. The flywheel contributes about 27% of the total frictional power consumed hence an increase in the size or weight of the flywheel should be given a serious thought before designing. In cases of high speed engines, the contribution of flywheel is more predominant. A more balanced engine may reduce the weight of the flywheel and this tends to decrease the flywheel contribution drastically even though the reduction in weight might be less.

The ring pack contribution follows a decreasing trend as the speed increases. The average contribution of middle piston ring is also very less compared to the other two rings. Reduction in the number of piston rings may well lead to a prominent drop in rubbing friction. A two piston ring approach can be considered rather than opting for a conventional three piston ring approach. This might well reduce, marginally, the cost of the engine also. Though the contribution of the piston, rings and connecting rod bearings seem to dip as the speed increases, it is found to be the major contributors accounting to about 70% of the total friction. The contribution of connecting rod assembly increases with speed. The temperature of the lubricating oil when maintained around 50 degree Celsius gave a slightly lesser frictional resistance. Though changing the temperature above and below this value did not have much of an impact as the contribution to rubbing friction increased only marginally and no substantial increase was found. Another point worth mentioning is that the temperature contribution when taken over a large period of time may contribute more to rubbing friction reduction. The contribution may be magnified when the engine undergoes an endurance test where the temperature contribution can be easily witnessed. Maintaining the oil temperature ensures good lubrication for a considerable time period and hence the change of oil may not be required frequently.

From the floating liner tests that generated crank angle versus piston ring and skirt frictional force graphs, it was evident that the rubbing frictional force decreased as the speed increased. Better splash lubrication when running at high speeds may be one of the reasons for this. Thus the contribution of piston ring pack and piston reduces as the speed increases. This is inline with the trend followed during strip down motoring tests.

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