

Investigations on Power Enhancement and Reduction in Particulate matter in Four Stroke Compression Ignition Engines

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Abstract— The internal combustion engine (I.C engine) are presently backbone of automotive space and they find applications mainly for transportation apart from being used for power generation. Power development constitutes a challenge as only portion of the heat developed is converted to power and the rest lost. Frictional power lost is accountable and although the development of I. C Engines are over a century; reduction of various losses remains a challenge to the designers and automotive experts. Applications ideally need a highly reliable and robust source of mechanical energy from automobiles, locomotives, aerospace to electrical power generators to define better amenities for future needs. The power realized from IC engines suffers from inherent parasitic power losses, resulting from the piston cylinder mechanism, valve actuation and accessory power take off drives. Several mitigating measures to reduce frictional power losses are being tried out by manufacturers and designers in the automotive engineering arena, the main cause for engine power parasitic loss. Same been tried out in the past and are in vogue.

Use of present technology being put to achieve power enhancement and friction reduction challenges is a motivation for this investigation work and to develop feasible measures which minimise the parasitic work losses.

Proposed project is intended to be carried out based on the methods which are tried out by various researchers and their approaches to reduce frictional losses and enhancement techniques for power.

This paper presents a literature review for the development journey into the various diesel engine power boosting/minimising Frictional Power Loss/Frictional Mean Effective power (FMEP) consumption techniques as well as aiming for a reduction in exhaust gas emissions. This work is proposed to model the design modifications with the suitable experimentation in a dynamic manner in a laboratory assisted under standard test conditions. Since the power cylinder unit (PCU) is the main cause for frictional loss, our focus in this paper will be to discuss the different design techniques used in the past as well as to explore future vistas. Proposed outcome is to develop an optimized cylinder liner design combined with a matching choice of engine lubricating oil grades tested under laboratory conditions.

Keywords— Internal Combustion Engine (I.C engine), FMEP Frictional Mean effective Power, PCU (Power Cylinder Unit), (WHR) Waste Heat Recovery, (VGT) Variable Geometry Turbocharger, BHARAT STAGE. (BS).

I. INTRODUCTION

The advent of global emission regulations has led to unprecedented and tight imposition of emission standards. Also customer satisfaction as regards to performance, driveability, operator comfort and fuel economy have been the topmost priority of engine and vehicle manufacturers.

Due to the extremely reliable and durable property of diesel engines, it continues to be a primary source of power in the industrial arena. However their negative impact on environment is not missed. Hence these factors drive the automobile ancillaries to devote their energies to conserve fuel, natural resources and limit the unwanted emission of particulate matter into the atmosphere. Hence manufacturers have started to use a plethora of technologies viz. VGT, variable valve timing actuation, common rail, EGR, electronic fuel injection, all of these co-ordinated by an ECU that uses scalar and vector calibration of engine combustion processes. In addition CFD modelling and experimentation on a single cylinder engine are the preferred platforms for the above. Increasing the power density of engines is a key to achieve improved durability, performance and enhanced productivity. Engine downsizing, downspeeding and hybridization all have their roles in power density improvement. For example, down speeding implies reducing engine speed to achieve a specific torque. Even a 100 RPM reduction can translate to a 1% reduction in fuel consumption. Hybridization offers more opportunities to use downsized engine power entities. Similarly usage of electrification reduces parasitic engine loads (such as friction) and at the same time, supplement available power. One of the most significant sources in reducing engine PM and NOx emissions is a correct choice of engine lube oil. Oil vaporization and combustion are the main consumption contributors for engine lube oil consumption. Synthetic grade 5W40 oil can reduce fuel consumption by 3% as compared to mineral oil 15W40. The rotating liner technology attempts to reduce boundary friction for piston ring interface and cylinder liner at the TDC points. This reduces friction and mechanical loss since the diesel engine causes more friction loss as compared to other IC engines. By this the major tribological impediment of friction @ elevated temperatures at piston ring liner junction finds a solution.

Oil consumption directly leads to PM and HC emissions. 90% of oil consumption occurs in engine cylinder.

Useful energy generated loses 13% to the wall and 18% heat losses to the cooling system. The engine water pump speed is a direct function of engine speed. The present day engine coolant pumps produce the appropriate coolant flow at only 5% of the time at high loads. Electrification of the water pump provides an opportunity to reduce a primary of parasitic power loss. Since the flow rate can be programmed, sudden flow pulsation and thereby power loss is prevented.

Engine cylinder liner surface topography optimization can largely help in reducing HC, CO, PM and NOx emissions from engine. Diamond honing stones offer a solution to the inner honing process.

Electric oil pumps permits pump operation at the desired flow rates @ corresponding speeds independent of engine speed. The engine oil pump size can be downsized and optimized. Such an oil pump can operated by remote control. Even pre-lubrication and post lubrication (after engine is switched off) can be achieved.

II. OBJECTIVES

- To conduct an engine performance test on existing diesel engine.
- To couple an induction motor to existing engine and monitor frictional HP at various speeds of rotation.[with fuel supply cut-off]
- To modify cylinder liner design and re-evaluate engine performance.

A. Methodology

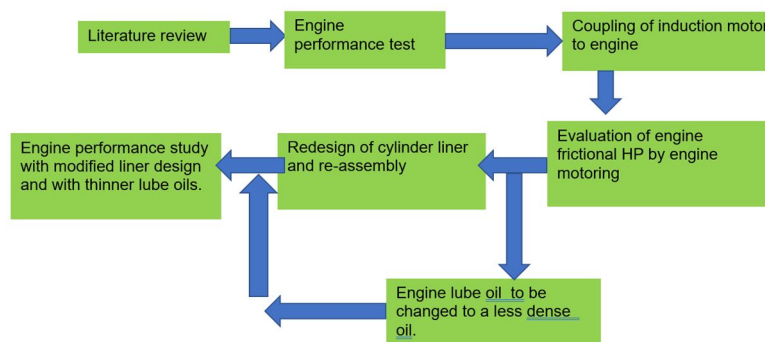


Figure 1

B. Experimental test rig



Figure 2

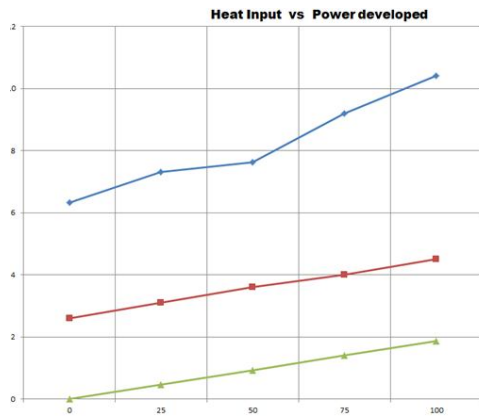


Figure 3

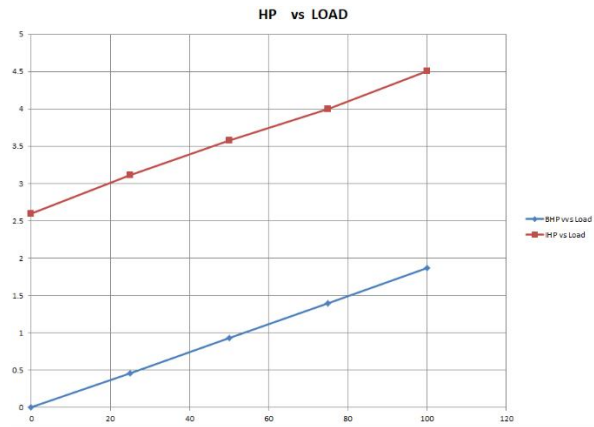


Figure 4 IHP, BHP vs Load

C. Layout of Engine After Induction Motor Mounting



Figure 5



Figure 6

Initial Test results reveal that only 30% of the heat can be converted to indicated HP

- There is a further 50% drop from IHP to BHP
- With an increase in load, thermal and mechanical efficiencies rise.
- The gap between the indicated and thermal thermal efficiencies is very large.
- Specific fuel consumption improves (reduces) with an increase in load.

- The losses encountered in heat supplied conversion to indicated HP include
- Piston – cylinder liner frictional and thermal losses especiall hen the pistonchanges its direction
- Heat losses to cylinder liner walls
- Heat losses to cooling water/coolant
- Heat lost via exhaust gas
- Radiative losses
- Engine air intake and exhaust pumping losses

III. RESULTS AND DISCUSSIONS

A. Modifications in engine cylinder Liner

The power cylinder unit , being the major contributor towards engine friction,(50%) , the cylinder liner is the prime component taken up , to reduce friction.

Friction loss is associated with the hydrodynamic regimes of engine oil occurring in the liner.

The speed of the piston is minimal at the Top dead center and Bottom dead center, namely the TDC and BDC areas. Now, at these areas, the direction of piston travel reverses. As a result, the speed of sliding is very less . Hence the coefficient of hydrodynamic friction is less. [1]

Application of an unique texture in the cylinder can be of significant importance. Thereby it is beneficial to reduce the density of texturing at the TDC and BDC and preferentially increase the same at the middle of stroke. Regarding the pattern of cylinder honing, as opposed to the plateau honing pattern that is being practised for quite some time, recent researches have confirmed the superiority of a comparatively smoother liner which has enabled a lesser consumption of lube oil. Thereby, a lesser quantity of lube oil consumed will result in a lesser emission of hydrocarbons , soot and particulate matter.

The roughness of cylinder liner is defined by the number of grooves, the distance between them, as well as their widths depths and determinable by the Hough's Transform.

As more oil evaporates, consumption of oil is bound to increase. Cylinder bore distortion can further the process of irregular oil consumption and vaporization. The circularity of cylinder bore can occur in four orders, viz. oval deformation, three-lobe and four lobe manner.

During the compression stroke and combustion phases, the compression and explosion pressure injects and induces the unburnt gas into crevices, intra spaces between piston, piston rings and cylinder liner walls. The gases are mainly unburned air-fuel mixture and those resulting from partial burning of lube oil in the piston-ring- liner clearances.

The effect of improved cylindricity in liner also have a very beneficial effect as regards to low oil consumption, hence paving the way for less PM in exhaust. Combined with correct piston ring matching , they can together reduce oil consumption by as much as 30%.

Hydrocarbon emissions are observed to increase with the increase in top land gap.

B. Usage of optimal grade of engine lube oil

Higher sized engines are expected to emit 0.5 ~1.5 gms/kW-hr of PM.

The useful work that is lost in countering Friction is estimated to be about 10% @ Full load and about 100% at idling. The same is dissipated and communicated to the surroundings in the form of heat losses to engine coolant and engine lubricating oil.

Selection of engine lube oil is very much important and essential to the process of friction reduction in an IC engine. [3]

Viscous friction torque is more pronounced during starting of engine. Viscosities of engine oil diminish with temperature increase, thereby reducing friction torque.

Lubricating oil viscosity needs to be kept high at TDC and BDC areas while reducing the same at mid stroke . This will reduce friction at the vantage points.

Use of LVEO (Low viscosity engine oils) has made its presence felt in both light vehicle as well as Heavy vehicle segments. The reduction of friction at the tribo-contact zones will ultimately translate in to proportional reduction in fuel consumption. Use of 5W30 oil is proven to reduce friction at higher entrainment speeds and higher loads. [4]

The surface temperatures at the contact are influenced by the combustion gases and heated engine oil by viscous shear of the lubricant film and more by the heat generated through contact friction. Therefore, a realistic model should encompass boundary interactions. The results confirm a viscous shear of the lubricant film under thermal mixed hydrodynamic regime of lubrication.

Synthetic lube oils tend to account for less emissions. For example use of 5W30(synthetic) oil is expected to emit less than a 15W40 grade oil(mineral base).

Synthetic oil contributes to the reduction of NO_x and particulate emissions. The emission of nitrogen oxides is related to aromatic hydrocarbons, which also affect the density of the engine oil. The use of mineral oils increases NO_x emissions by about 8%.

C. Augmentation of electric oil pumps.

A number of other miscellaneous techniques for reducing friction include, optimized volume of cooling system, lubricating oil system & reduced air intake swirl. A reduced volume of coolant means lesser fluid to circulate, lower powered water pumps.

The same reasoning holds good for engine lube oil. One can make use of downsized lube oil pumps and hence lesser parasitic load on engine.

A reduced air intake swirl implies reduced friction loss to be countered during suction stroke and hence, lesser pumping losses. Also a lesser amount of swirl ensures lesser tendency of nitrogen oxide formation in exhaust, since there is less turbulence in intake air –fuel mixing and a more predictable flame travel pattern through the entire cycle.

Engine oil pumps are driven from a gear drive mounted on the front gear case in a standard engine. The flow varies directly as a function of engine speed. The oil pressure relief is required to regulate oil flow, at a cost of associated energy loss. A reduction in engine pumping power will benefit fuel consumption since the engine will consume less power to drive the oil pump. Engine oil pumps can be of external or internal gear types.

In order to optimise engine lubrication system and reduce power consumed, oil pumps can be electrically driven instead of being mechanically driven through gears which entails a good amount of friction and heat. Low speed pumps tend to be higher in size. High speed pumps can be of lesser size.

Electric pump is one way to reduce parasitic loss and can be preferred for lower FC. [8]. With Electronic control, oil flow demand can be met. Pump size can be reduced. The subject pump can be remotely mounted. Pre-lubrication and post lubrication can be facilitated. Same is required since engine can be lubricated prior to starting. Also when the engine is switched off, lubrication is still possible in turbocharger for some duration.

D. Electric water pump drives.

Out of the total energy produced by the diesel engine, nearly 13% is lost by exhaust heat losses to the wall and 18% wall heat losses which must be dissipated by a heat transfer means, to lower the engine's temperature. The water pump can be either mechanically or electrically driven to circulate the coolant fluid around the engine in this cooling system.

Coolant Leakage, vane disk friction and water pump bearing losses all contribute to the difference between actual power and theoretical power for the working coolant fluid transfer.

Hence, an electric water pump is becoming a more sensible alternative to the mechanical counterpart, to reduce the above said losses.

An electric water pump has a chance to remove a source of parasitic loss from the internal combustion engine and provide a better control of the engine temperature according to the engine cooling requirements.

Electric pump offers an effective flow control which is independent of engine speeds, hence it can lower the system operating requirement with a reduced pump flow rate at high engine speeds. This allows the engine to run at a more steady temperature, Also, there is no sudden fluctuation in the coolant flow rate that reduces losses.

The gear drives of the mechanical water pump place large acceleration provoked forces into the pump shaft due to the gear teeth meshing which generates high cyclic loads. The belt driven water pumps do not have the same accelerations as the gear driven ones, but the belt driven water pumps can experience larger side loads due to the drive belt tension. Both of these 'driving' factors require the mechanical water pumps to have large bearings leading to high bearing loads. Electrical pumps ensemble a drive motor in line with the impeller eliminating the need for large bearings and in some cases coupling used between the motor and pump which further reduces the pump drag friction loss.[9] An electric pump is able to circulate coolant fluid throughout the engine post shutdown which enables one to control the engine's thermal mass to prevent the overheat of critical components. Hence by using electric water pump, drive gears, belts, pulleys, etc. can be eliminated and engine can also run cooler as compared to conventional water pump

E. Rotating Liner Engine

The Rotating Liner Engine (RLE) concept is a design concept for internal combustion engines, where the cylinder liner rotates at a surface speed of 2–4 m/s in order to assist piston ring lubrication.

The metal-to-metal contact/boundary friction that exists close to the piston reversal areas, is significant. This frictional source becomes a significant energy loss, especially in the compression/expansion part of the cycle, when the gas pressure that loads the piston rings and skirts is high.

It is generally recognized that the frictional losses in engines are directly correlated to the high temperature and high shear rate of the lubricant. As the hot oil is sheared by the fast sliding and low film thickness surfaces, it undergoes a temporary reduction in operating viscosity, and it is this reduced viscosity

Under high shear rate, the molecules of the lubricant align with the predominant direction of sliding, reducing the actual viscosity. This reduction can be beneficial in areas where pure hydrodynamic lubrication is taking place. However, it can also be detrimental in the areas close to transition from hydrodynamic into mixed.

The Diesel Rotating Liner Engine proto derived from a Cummins 4BT engine and preliminary observations that emerged from low load testing. The new lubrication mechanism is generated by continuous motion of cylinder relative to piston under which high shear ratio, the lubricant aligns with the direction of sliding, reducing actual viscosity.[12]

At areas close to the TDC, the cylinder pressure is very high. As the piston descends, predominant shear rate is at an angle to the one already on the cylinder wall. This forces an increase in effective viscosity which is of use in mixed lubrication regime. During testing 5W30 oil was used that can be sealed by a face seal easily. An externally driven bevel gear box & belt pulleys were used to transmit power.[14]

Standard 5w30 low-viscosity light-duty lubricant was used during evaluation tests. The reason for choosing the above grade was that it was expected that the locosity would amplify the boundary terms. A piston friction reduction to reduce total engine friction by

50 kPa or more is possible. Fig 5 Liner press fitted with gear to be driven for rotation



Figure 7

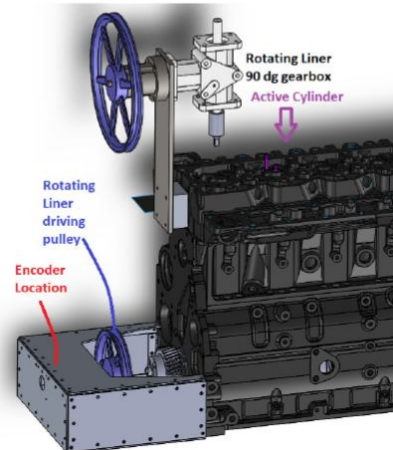


Figure 8 Drive for Rotating liner

IV. CONCLUSIONS

- Frictional Power loss in a diesel engine is the main source of mechanical loss(45%) and increases with cylinder wall friction.
- Down speeding and engine downsizing reduce friction.
- Recent engine improvements integrate the rocker arm housing and exhaust manifolds on to Cylinder head.
- Electrically actuated water pumps and engine lube oil pumps help to overcome engine parasitic losses.
- Smooth liners account for lower oil consumption than a plateau honed liner.
- Synthetic lubricating oils emit upto 13% less Hydrocarbon (HC) than mineral oil based such as 15W40 grade oil.
- Unburnt/partially burned engine lube oil is direct source for PM and HC emissions.
- Motored engine tests are an effective method to evaluate engine friction.
- Reducing engine intake swirl, volume of cooling and lubricating oil system, specially honed liners coupled with optimized & reduced number of piston rings contribute to more engine power and a lesser oil consumption.

- Soft wares like AVL BOOST, GT POWER & GT-SUITE are used to predict engine performance and emissions.
- The Rotating Liner Engine (RLE) is a promising concept in reducing engine friction.

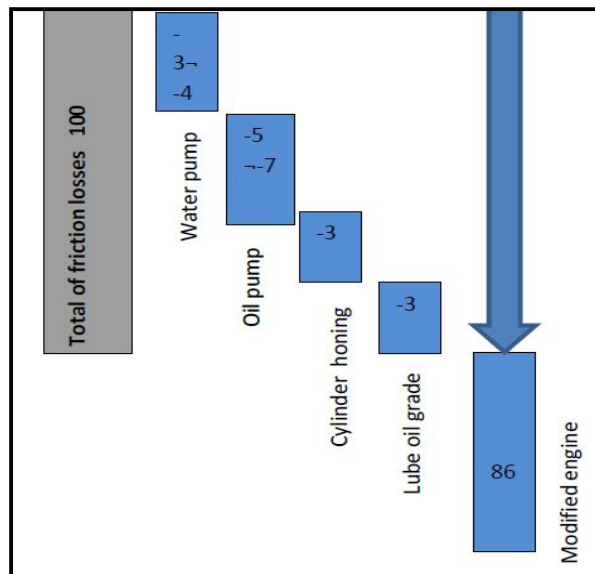


Fig 9 Estimated engine friction reduction

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