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Tribology of Prime Movers: IC Engine

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Basically, the function of a prime mover is to convert the input energy into a useful work. Thus, all types of engines & electric motors are known as a prime mover & used to get the useful work by utilising the input energy. The engine convert heat into work by expansion or increase in volume of a working fluid into which heat is introduced by combustion of a fuel either external to the engine as in a steam engine or internally by the burning of a combustible mixture in the engine itself known as ‘internal combustion engine’ (ICE) or a jet engine. For easier understanding of the engine tribology aspects, an automobile engine is selected here as the prime mover.

The reciprocating internal combustion engine are popular, reliable & versatile with a large range of power units available in both petrol and diesel engines as applicable to bike, scooter, car, jeep, van. truck, tractor, bus, mid to light duty trailers, off highway trucks, train, boat, ship, agriculture-domestic pumping, construction & mining vehicles & machinery etc. as per their needs. LPG & CNG engines are in automobile operations. Hydrogen engines are now used on trial basis.

The largest number of ICE are used in cars, jeeps (SUVs), light & heavy-duty vehicles world over among the others. Thus, a typical case of petrol engine is referred here. The data collected from various published studies on the energy distribution are shown as an average values applicable for petrol cars worldwide. Typical distribution of the mechanical friction losses ~78% in a petrol engine car are as shown in Fig-1 (ref. Pinkus & Wilcock, lang, Anderson, Bartz, Taylor, Hikita, Holmberg et al-2012).On the other hand, typical fuel energy dissipation of ~ 74% in a Petrol car is shown in Fig-2.

With the new technology & tribology in passenger cars, friction losses could be reduced by 18% in the short term (5–10 years) as per Holmberg et al. This would equal worldwide economic savings of 174,000 million euros; fuel savings of 117,000 million litres and CO_2 emission reduction of 290 million.

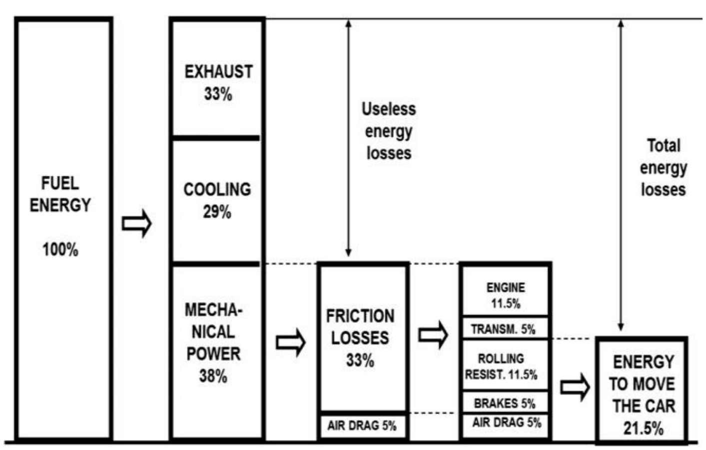


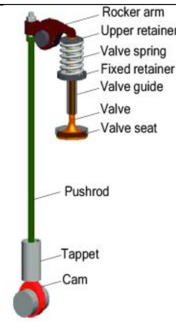
Fig.-1: Distribution of energy in a typical passenger Petrol carr

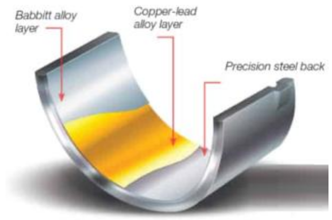
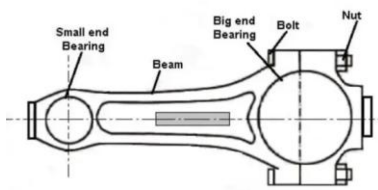
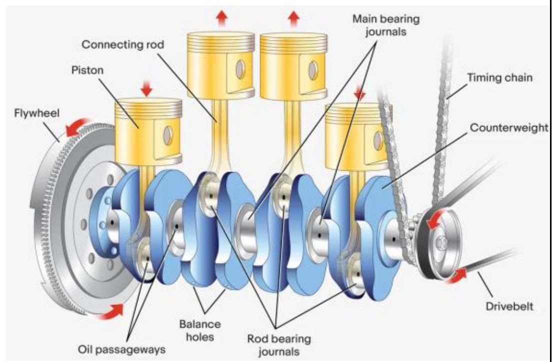
Energy Input	Energy Loss	% Loss
Fuel (Potential Energy)	Exhaust	33%
	Cooling	29%
	Engine Friction	12%

Conversion to:
1.Kinetic Energy: Motion
2.Thermal Energy: Heat loss
3.Fuel potential energy reduction

Fig-2: Typical fuel energy dissipation in a Petrol car

Table-1: Main engine components subjected to friction & wear

Piston & Rings	Cylinder (Liner)	Cam Shaft	Valve Train
			

Engine bearings	Insidious components of engine
 Connecting Rod 	

Impact of friction: The main frictional losses in an engine are due to friction between the piston with the cylinder walls, friction in various bearings, camshaft, crankshaft, valve train as shown in table-1 and also the energy spent in operating the auxiliary equipment such as cooling water pump, ignition system, fuel pump, fan, alternator etc.

The Piston Ring Assembly (PRA) Friction: PRA friction may best be characterized by the simple reciprocating motion of the piston within the liner, leading to areas of mixed and boundary lubrication at top and bottom dead centre followed by the regions of lubrication in between as shown in table-2. Due to combustion the pressure inside the cylinder increases which promotes higher friction. The tribological studies of the piston ring friction zone, viscous shear which incorporate mixed lubrication conditions & wide variation with a host of influential parameters like temperature etc.

VALVE TRAIN FRICTION: The valve train friction occurs in the cam/follower interface, cam bearings/ seals, rocker arm, pivots, and tappets. The cam interface, tappet and bore friction account for the majority of friction. The valve train frictional losses typically account for 7% to 15% of the total mechanical losses of engine. In heavy-duty engines, the valves are usually operated by means of push-rods and rockers that receive their motion from a crankcase mounted camshaft.

ENGINE BEARING FRICTION: Different components of engine causes bearing frictions e.g. the crankshaft main bearings, connecting rod big-end & small-end bearings, camshaft bearings, and rocker arm bearings. High loadings in these bearings can be supported along with low friction due to complete separation of moving parts by a thick lubricant film. Engine bearings account for 20 to 30% of the total engine frictional losses. The highly stressed bearings in the engine are in the connecting rod big-end/small-end bearings and the crankshaft main bearings.

Table-2: Engine Friction Energy Loss Distribution

	Hydrodynamic Lubrication (HDL)	Elasto-Hydrodynamic-sliding contact Lubrication (EHDS)	Mixed Lubrication (ML)	Boundary Lubrication (BL)
Petrol Car	40 %	40 %	10 %	10 %

Table-3: Engine Friction Energy Loss Distribution in its main components

Engines used in	Piston assembly	Bearings and Seals (HD)	Valve Train (ML)	Pumping and Hydraulics Viscous Losses (VL)
Passenger Cars	45% (45–55%)	30% (20–40%)	15% (7–15%)	10%

ENGINE AUXILIARY POWER LOSSES: Engine auxiliary power losses come from built-in accessories such as coolant pumps, oil pumps and fuel injection pumps, fans, alternators, air conditioning, and power-steering pumps.

FUNCTIONSOFENGINELUBRICATING OIL: Lubrication is an ancient art and modern science. In ICEs, high shear rates and high stress are generated in bearings and liner-piston-ring zones. Lubricants for engines need to fulfil several important functions in addition to the best known – controlling friction and wear to protect the engine against rusting, cooling & sealing the piston-ring-liner surfaces, against leakage of the combustion gases & cleaning by minimizing deleterious effects of combustion products etc. The lubricant has to perform these functions for periods of hundreds of hours between oil changes, under a wide variety of climatic and operating conditions. In today's trend of high power to weight ratio engines of compact size deliver high power, causes extreme thermal stressing and oxidation of the engine oil. The oil must remain fluid under all these conditions to perform its functions, ideally maintaining the right physical properties to perform them efficiently. Premium quality engine oil is formulated with a top-quality base oil with advanced technology-based additives in order to protect the automotive engine. ICE oils are graded based on the Society of Automotive (SAE) standard, which groups oils according to their viscosity.

Impact of temperature on the engine: ICEs are an interesting illustration of variation in temperatures in a machine and the corresponding times of exposure of the lubricants to those temperatures. There have been dramatic improvements in the life of engine oils in the past 70 years. In a typical passenger car, the engine oil change period was at 1500 Km in 1949, but this increased to 10,000 Km by 1972 and about 15,000 Km by 1998 owing to the use of synthetic oils. The general trend to higher specific power leads to higher operating temperatures. Different lubrication zones in the engine components are- 1) Engine bearings and seals mainly operate under hydrodynamic lubrication (HD), 2) The valve train operates under mixed lubrication (ML), which combines: a) Hydrodynamic lubrication (HD), b) Elastohydrodynamic lubrication (EHD) & c) Boundary lubrication (BL). The most critical is boundary lubrication zone, where the oil film is so less & thin that ultimately the resultant rough surfaces make frequent contacts that leads to higher friction. Based on various sources, the engine friction energy loss distribution as shown in table-3.

Tribology Solutions

Smart & energy efficient oils: Nowadays the trend is to use low viscosity oils like 5W-30, 5W-20, 02W-20 etc. in place of 20W-40, 15W-40 viscometrics engine oils used previously. Thus, the high temperature high shear viscosity of the gasoline engine oils is reducing to 2.6 cSt.- 2.9 cSt. as against in the past of 3.7 cSt. Advantage of using low viscosity oil actually reduces the viscous drag thus it lowers the fluid friction that gives better fuel economy.

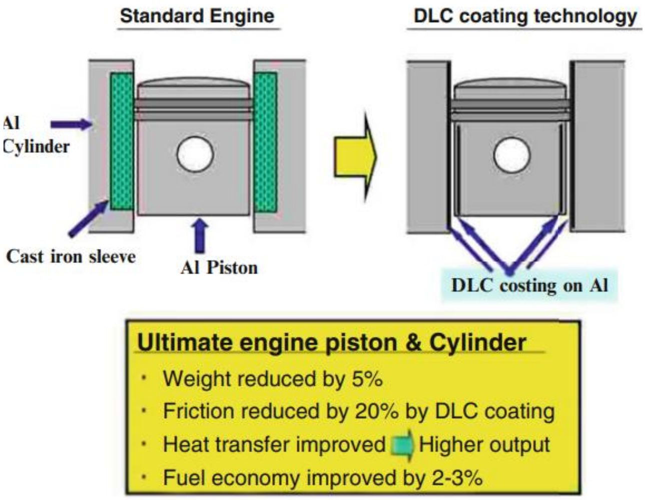


Fig-3: DLC coated aluminium alloy piston & cylinder for ultra-low friction engine

Different types of special additives e.g. Anti Wear (AW), Extreme Pressure (EP) & Friction Modifier (FM) are added in the lubricating oil. The addition of friction modifier additives like glycerol mono-oleate (GMO) to a polyalphaolefin (PAO) oil gave a friction coefficient of 0.05 in sliding contact. Of late, the use of certain nanomaterials as anti-friction and anti-wear additives has given very promising results. Customised oils are designed for the specific use of railroad engines, marine engines etc.

Low friction coatings for engine components: During the past two decades, research on low-friction materials and coatings has intensified, mainly because the traditional solid and liquid lubrication approaches would not alone meet the increasingly more stringent operational conditions of modern mechanical systems, including engines. A tribometer test indicated that significant reduction in hydrodynamic friction is achieved by applying textures (creating dimples on its surfaces) on cylinder liner surfaces & also on the piston skirts. The resultant friction is further reduced by using different oil additives along with low-friction DLC coatings as shown in Fig-3.

Smart metals: the connecting rods & valve train components made from titanium alloys are used in racing car engines to reduce the reciprocating weight without compromising the strength. Insulation of combustion chamber by

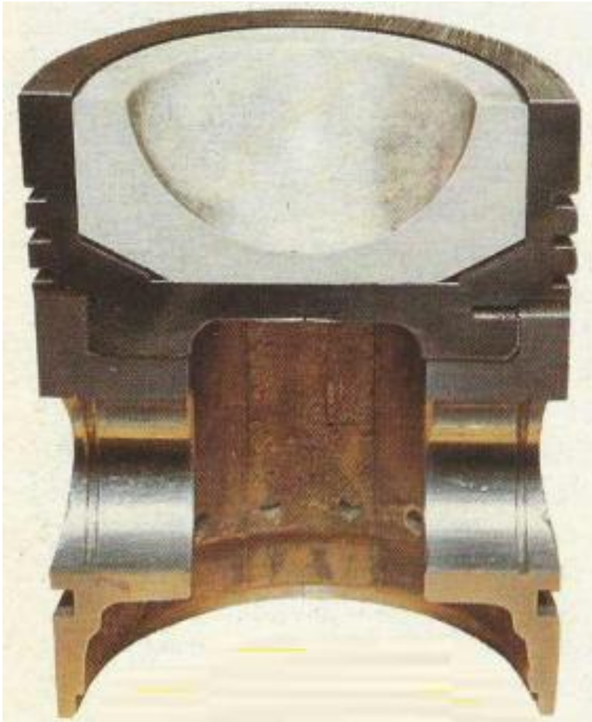


Fig-4: Ceramics used as inserts in piston crowns

ceramics, as inserts are applied to reduce the heat loss to gain the thermal efficiency & also to reduce the required radiator capacity, Fig-4. Ceramic turbocharger rotors exploit their lower material density & hence reduced inertia by showing reduced response time. Insulation of exhaust ports to reduce the heat rejection to coolant & improve the turbocharger efficiency by increasing the temperature of the exhaust gases. ◆

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