Internal Combustion Engines

Engine Friction

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Engine Friction

The frictional processes in an engine can be classified into three categories viz.,

(a) the mechanical friction, which includes friction between internal moving parts such as crankshaft, piston rings, valve train etc.

(b) the pumping work, that is the work done during the intake and the exhaust strokes,

(c) the accessory work, which is required for the operation of engine accessories such as oil pump, fuel pump, fan etc.
Mechanical Friction

Motion between engine components, highly magnified to show the surface roughness

(a) Dry or non-lubricated surface showing friction caused by high spots.

(b) Lubricated surface showing reduction of friction by hydraulic floating.
Mechanical Friction

Three important characteristics that are needed in a lubricating fluid are:

- It must adhere to the solid surfaces.
- It must resist being squeezed out from between the surfaces, even under the extreme forces experienced in an engine between some components.
- It should not require excessive forces to shear adjacent liquid layers. The property that determines this is called viscosity.
Lubrication of bearings. (a) Non-rotating, lubricating oil is squeezed out and surface contacts surface, (b) Rotating, oil film is dragged by moving surface and surfaces are separated by thin layer of fluid.
Engine Friction

Friction can be expressed as a loss using the power terms:

\[ fp = ip - bp \]

Further, mechanical efficiency can be defined as

\[ \eta_m = \frac{bp}{ip} = \frac{bmea}{imep} \]
As engines of varying sizes can operate at different speed levels, the most meaningful way of classifying and comparing friction and engine losses is the mean effective pressure (mep). In some analyses, mep concept is expanded to include all work and power inputs/outputs of an engine.

\[ fmep = imep - bmep - amep - cmep + tmep \quad (1) \]

where,

- \( fmep \) = work lost to internal friction
- \( imep \) = net work generated in the combustion chamber
- \( bmep \) = work available at the crankshaft
- \( amep \) = work required to drive auxiliaries
- \( cmep \) = work required to drive supercharger/turbocharger
- \( tmep \) = work recovered from the exhaust gas in a turbocharger turbine
\[ fmep = imep - bmep - amep - cmep + tmep \]  \hspace{1cm} (1)

When \( amep = 0 \)

and \( cmep = tmep \)

the expression (1) reduces to

\[ fmep = imep - bmep \]

**Remark:** The magnitude of friction mean effective pressure (or friction power, or friction work) is of the order of 10% of net indicated mean effective pressure at wide open throttle. This increases to 100% at idle, when no brake power is taken off the crankshaft. A turbocharged engine has a lower amount of friction loss. This is due to the greater brake output, while absolute friction remains the same. Most power lost to friction usually ends up heating the lubricating oil and coolant.
It is much difficult (and less accurate) to divide total friction into parts. One way is to motor the engine. When an engine is motored, the ignition is turned off and no combustion takes place.

Unlike a fired engine, both the compression-expansion loop and the exhaust-intake loop of this cycle represent negative work on the cylinder gases.
Motoring Method

- In this method, initially the engine is run in a normal fire mode. When the engine reaches a steady-state condition with all temperatures, it is turned-off and immediately tested using an electric motor.

- For a brief period of time, the engine temperatures will be almost same as with a fired engine. This will quickly change because no combustion is occurring, and the engine starts cooling-off.

- Hot combustion products that make up the exhaust flow in a fired engine are approximated with much cooler air in a motored engine.
Friction losses for various engine components as measured by motoring of the engine.

Figure gives typical results for the percentage of friction contributed by various engine components.

All losses which are given in terms of fmep increase with engine speed.
The components that contribute a major part of total friction are the pistons and piston rings.

Figure shows the friction forces on a typical piston assembly as it traverses one cycle.

The forces are greatest near TDC and BDC where the piston momentarily stops.
In above figure, motoring mean effective pressure (mmep) is plotted as a function of average piston speed. In X-axis, piston speed can be replaced with engine speed without changing the shape of the curves.
Side thrust force (STF) is a reaction to the connecting rod (CR) force and is in the plane of the CR. When the piston passes BDC, the STF switches to the other side of the cylinder. The CR force and the resulting STF are greatest during the power stroke and this is called the major thrust side. Lesser forces during the exhaust stroke occur on the minor thrust side. The friction force is in the opposite direction to the piston motion and changes direction after TDC and BDC.
Forces on a piston

\[ \sum F_x = m \left( \frac{dU_p}{dt} \right) = -F_r \cos \phi + P \left( \frac{\pi}{4} \right) B^2 \pm F_f \quad (2) \]

where
- \( \phi \) = angle between the connecting rod and centerline of the cylinder
- \( m \) = mass of piston
- \( \frac{dU_p}{dt} \) = acceleration of piston
- \( F_r \) = force of the connecting rod
- \( P \) = pressure in the combustion chamber
- \( B \) = bore
- \( F_f \) = friction force between the piston and cylinder walls
The sign of friction force ($F_f$) term depends upon the crank angle $\theta$.

- when $0^\circ < \theta < 180^\circ$
- when $180^\circ < \theta < 360^\circ$

There is no motion in Y direction, so a force balance gives

$$\sum F_y = 0 = F_r \sin \phi - F_t \quad -(3)$$

Combining (2) and (3), the side thrust force on the piston becomes

$$F_t = \left\{-m \left( \frac{dU_p}{dt} \right) + P \left( \frac{\pi}{4} \right) B^2 \pm F_f \right\} \tan \phi \quad -(4)$$
Forces on a piston

- To reduce friction, modern engines use pistons that have less mass and shorter skirts. Less mass lowers the piston inertia and reduces the acceleration term (equation 4). Shorter piston skirts reduce rubbing friction because of smaller surface area contact.

- Some manufacturers opt for a shorter stroke length to minimize friction. However, for a given displacement this requires a larger BORE. This results in greater heat loss due to larger cylinder surface area. Greater flame travel distance also increases the knock problems. This is why most medium-sized engines are close to square with $B \approx S$. 
Effect of Variables on Friction

1. **Stroke to Bore Ratio:** Engines with a lower stroke-to-bore (L/B) ratio tend to have a less friction mean effective pressure (fmepr) mainly due to its lower surface area.

2. **Cylinder Size and Number of Cylinders:** The friction and economy improves when a smaller number of larger cylinders are used. This is because the ratio of the piston face area to its skirt area is reduced. Thus for the same total displacement, a four cylinder engine will be more efficient than a six cylinder engine.
Effect of Variables on Friction

3. Compression Ratio: The fmep increases with the increase of compression ratio. However, the mechanical efficiency either remains constant or improves because of increased indicated mean effective pressure (imep).

4. Engine Speed: Engine friction increases rapidly with the increase of engine rotational speed. The mechanical efficiency deteriorates considerably at higher engine speeds. Hence, there is a restriction to limit the engine speeds.
5. **Engine Load**: With the increase of load, the maximum pressure in the cylinder, and hence the frictional losses in an engine increase. However, the maximum pressure and hence the temperature reduces the viscosity of the oil. This reduces the friction slightly.

6. **Oil Viscosity**: Viscosity of oil and friction losses are proportional to each other. By raising the oil temperature, the viscosity can be sufficiently reduced. However, beyond a certain value, oil film might crack leading to metal-to-metal contact causing damage to the engine.
Effect of Variables on Friction

7. **Coolant Temperature**: A rise in cooling water temperature reduces engine friction through its effect on oil viscosity. Friction losses are high at the time of starting as the coolant and the oil both are at the low temperature with the oil having a higher viscosity.
Conclusions

Because of friction, engine brake power is less than the power generated in the combustion chambers. The loss of useful power is mainly due to two types of friction viz., mechanical friction that occurs between the moving parts, and fluid friction resulting from the intake and exhaust systems, flow through valves, and fluid motion within the cylinders. More often operation of engine accessories, powered directly or indirectly, also forms a part of friction load, and this reduce the final power output.
References

Web Resources

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