Engine Friction and Lubrication

Engine friction
- terminology
- Pumping loss
- Rubbing friction loss

**Engine Friction: terminology**

- Pumping work: $W_p$
  - Work per cycle to move the working fluid through the engine
- Rubbing friction work: $W_{rf}$
- Accessory work: $W_a$

Total Friction work: $W_f = W_p + W_{rf} + W_a$

Normalized by cylinder displacement → MEP
- $tfmep = pmep + rfmepe + amep$

Net output of engine
- $bmepe = imepe(g) - tfmep$

Mechanical efficiency
- $\eta_m = bmepe / imepe(g)$
Friction components

1. Crankshaft friction
   - Main bearings, front and rear bearing oil seals
2. Reciprocating friction
   - Connecting rod bearings, piston assembly
3. Valve train
   - Camshafts, cam followers, valve actuation mechanisms
4. Auxiliary components
   - Oil, water and fuel pumps, alternator
5. Pumping loss
   - Gas exchange system (air filter, intake, throttle, valves, exhaust pipes, after-treatment device, muffler)
   - Engine fluid flow* (coolant, oil)

*Have to be careful to avoid double-counting. The engine coolant and oil flow losses are provided for by the oil and water pump. The nature of the loss is a pumping loss though.
Fig. 13-1
Comparison of major categories of friction losses: fmep at different loads and speeds for 1.6 L four-cylinder overhead-cam automotive Spark Ignition (SI) and Compression-Ignition (CI) engines.
Pumping loss

Fig. 13-15 Puming loop diagram for SI engine under firing conditions, showing throttling work $V_d(p_e-p_i)$, and valve flow work.

SI Engine losses

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Sliding friction mechanism

Energy dissipation processes:
• Detaching chemical binding between surfaces
• Breakage of mechanical interference (wear)

Bearing Lubrication

FIGURE 13-2
Schematic of a lubricated journal and a slider bearing.
**Stribeck Diagram for journal bearing**

$$f = \alpha f_s + (1 - \alpha)f_L$$

Hydrodynamic lubrication

Mixed lubrication

Boundary lubrication

Hydrodynamic friction $$(1 - \alpha)f_L$$

Solid friction $\alpha f_s$

Sommerfeld No. $= \mu N/\sigma$

Increasing load, decreasing speed

Decreasing load, increasing speed

**Motoring break-down analysis**

**Fig. 13-14**
Motored fme p versus engine speed for engine breakdown tests.
(a) Four-cylinder SI engine.
(b) Average results for several four- and six-cylinder DI diesel engines
Breakdown of engine mechanical friction

Valve train friction

Valve train friction depends on:
- Total contact areas
- Stress on contact areas
- Spring and inertia loads
Low friction valve train

FIGURE 13-25
Low friction valve train.\textsuperscript{22}

Valve train friction reduction

“Friction loss reduction by new lighter valve train system,”
JSAE Review 18 (1977), Fukuoka, Hara, Mori, and Ohtsubo
**Piston ring pack**

**Piston ring-pack dimensions**

**Vertical Motion:**
- Stroke ~ 100 mm
- Mean Piston Speed ~ 10 m/s ~ 20 mph
- Peak Piston Acceleration ~ 10,000 m/s² ~ 1000 g

**Lateral Motion:**
- Displacement ~ 100 µm
- Velocity ~ 10-100 mm/s

**Cylinder Liner:**
- Liner Roughness ~ 0.1 µm
- Bore Distortion ~ 100 µm ~ 0.1 mm

**Ring Pack:**
- Ring free shape deviation ~ 1 mm
- Ring face shape deviation ~ 10 µm
- Oil film thickness ~ 1 µm
- Ring height 1.2-1.5 mm
- Ring gap ~ 0.2 mm

**Piston Skirt:**
- Skirt shape deviation ~ 100 µm
- Ovality ~ 100 µm
- Tooling marks/waviness ~ 5 µm depth, 1/25 slope
- Roughness ~ 0.01 µm
- Thermal deformation ~ 100 µm
- Mechanical deformation ~ 100 µm

Source: MIT Sloan Automotive Laboratory.
Hydrodynamic lubrication of the piston ring

Friction force and associated power loss

FIGURE 13-18
Schematic of pressure distribution in the lubricating oil film and around a compression ring during expansion stroke. Pressure profile in the oil film indicated by horizontal shading.
Piston slap

FIGURE 17
Piston motion near TDC firing with piston-pin
Offset toward major-thrust side. (by 1-2% of bore)

Change timing (earlier) of transition so that the cylinder pressure at transition is lower – less force to accelerate piston

Transition is a “roll over” so that slap is less severe

Also the “slap” force is lower

Bore distortion

FIGURE 11
Three orders of bore distortion.

FIGURE 12
Top deck of hypothetical engine.
Lubricants

- Viscosity is a strong function of temperature
- Multi-grade oils (introduced in the 1950’s)
  - Temperature sensitive polymers to stabilize viscosity at high temperatures
    - Cold: polymers coiled and inactive
    - Hot: polymers uncoiled and tangle-up: suppress high temperature thinning
- Stress sensitivity: viscosity is a function of strain rate

Viscosity

(From Linna et.al, SAE Paper 972892)

10W30 refers to upper viscosity limit equal to single grade SAE 10 at 0 deg F (-18C) and lower viscosity limit equal to SAE single grade 30 at 100 C.
Additive to lubricant

• VI Improvers
  – To improve viscosity at high temperature
• High temperature stability
• Acid neutralization
• Detergents and dispersants
  – To keep partial oxidation products and PM in suspension and to prevent lacquer formation
• Anti-wear additives
  – E.g. Zinc dialkyldithiophospate (ZDDP)
  – Formation of anti-wear film

Modeling of engine friction

• Overall engine friction model:
  – tfmep (bar) = fn (rpm, V_d, v, B, S, ....)
  – See text, Ch. 13, section 5; SAE Paper 900223, ...

    ➢ For engine speed N:
      • tfmep = a + bN + cN^2

• Detailed model:
  – see text Ch. 13, section 6; SAE Paper 890936

\[
\text{tfmep} = \sum (\text{fme}\text{p})_{\text{components}}
\]

With detailed modeling of component friction as a function of rpm, load, ...
Distribution of FMEP for a 2.0L I-4 engine; B/S = 1.0, SOHC-rocker arm, flat follower, 9.0 compression ratio

- C = crankshaft and seals
- R = reciprocating components
- V = valve train components
- A = Auxiliary components
- P = Pumping loss

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