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: $W_{tf} = W_p + W_{rf} + W_a$

Normalized by cylinder displacement $\rightarrow$ MEP

- tfmep = pmep + rfmep + amep

Net output of engine

- bmep = imep(g) – tfmep

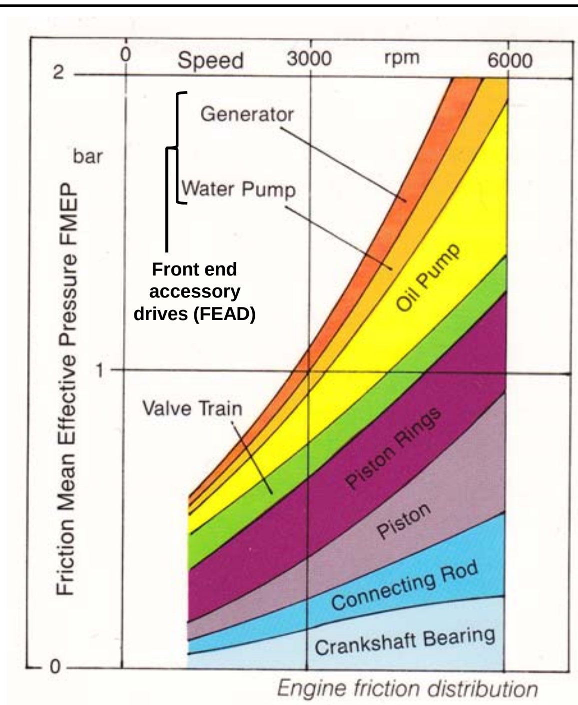
Mechanical efficiency

- η_m = bmep / imep(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.**



SI engine friction

(excluding pumping loss)

Source: FEV Brochure

Engine Friction

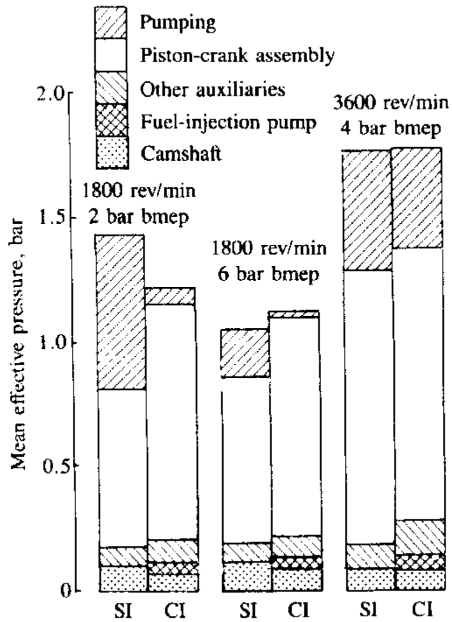


Fig. 13-1

Comparison of major categories of friction losess: fmep at different loads and speeds for 1.6 L four-cylinder overhead-cam automotive Spark Ignition (SI) and Compression-Ignition (CI) engines.

Fuel energy accounting for SI engine

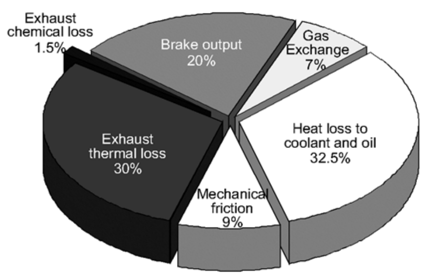


Figure 1. Typical engine losses at part load

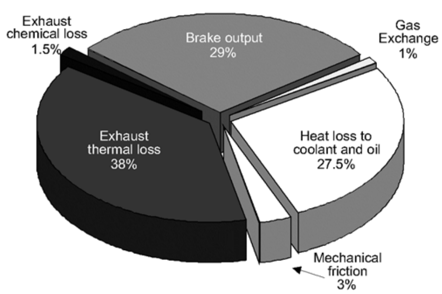


Figure 2. Typical engine losses at full load

SAE Paper 2000-01-2902

Pumping loss

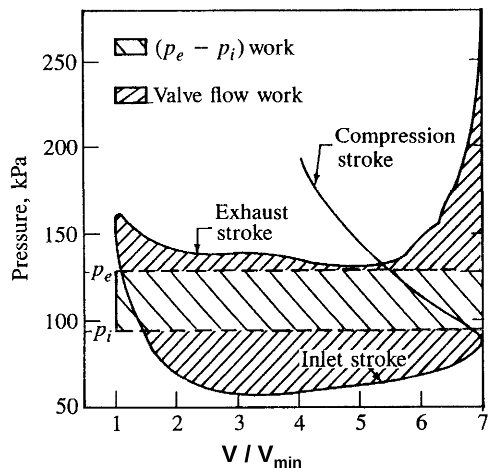
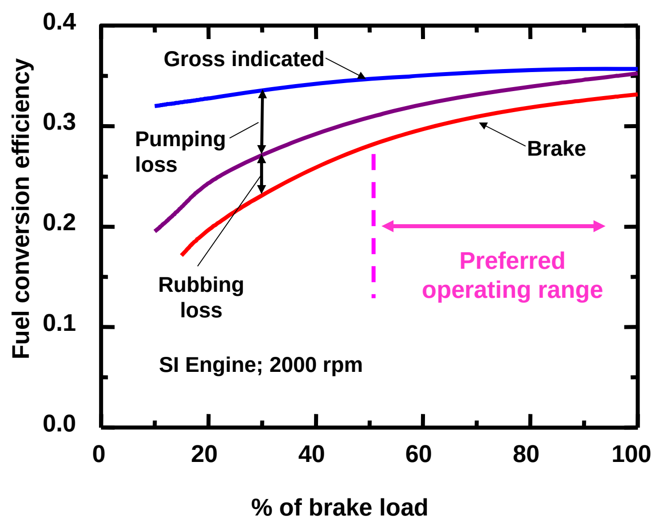
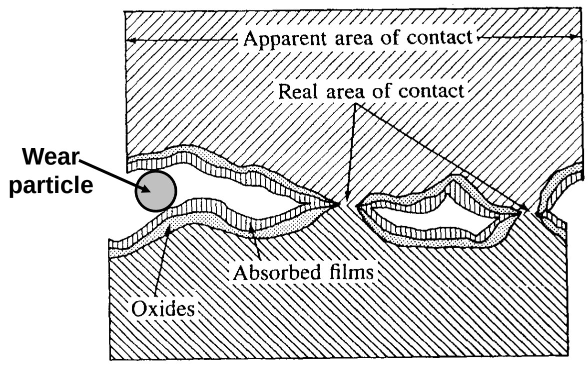


Fig. 13-15 Puming loop diagram for SI engine under firing conditions, showing throttling work $V_d(p_e-p_i)$, and valve flow work

SI Engine losses



Sliding friction mechanism



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

Bearing Lubrication

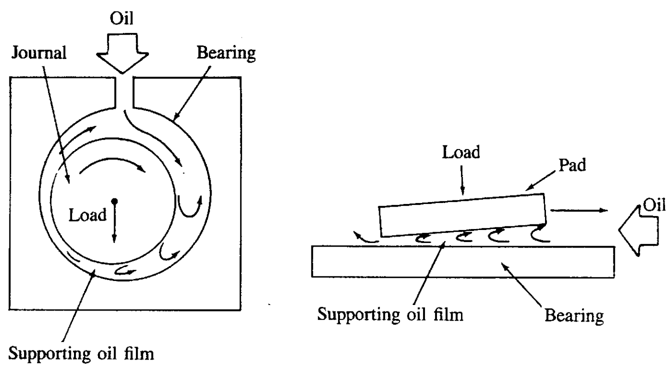
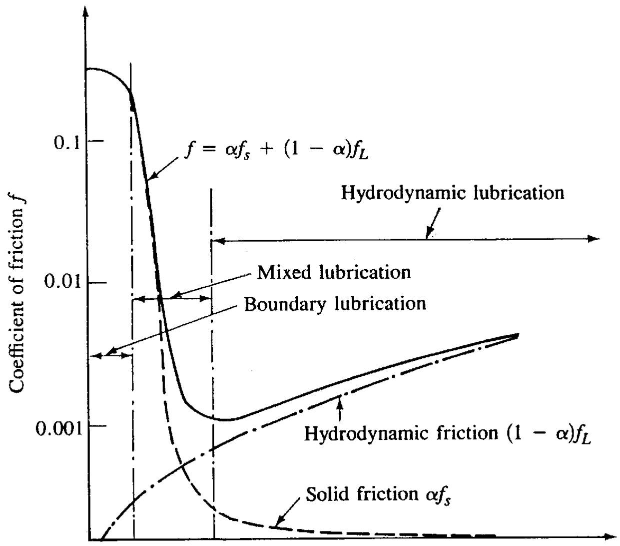


FIGURE 13-2
Schematic of a lubricated journal and a slider bearing.

Stribeck Diagram for journal bearing



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

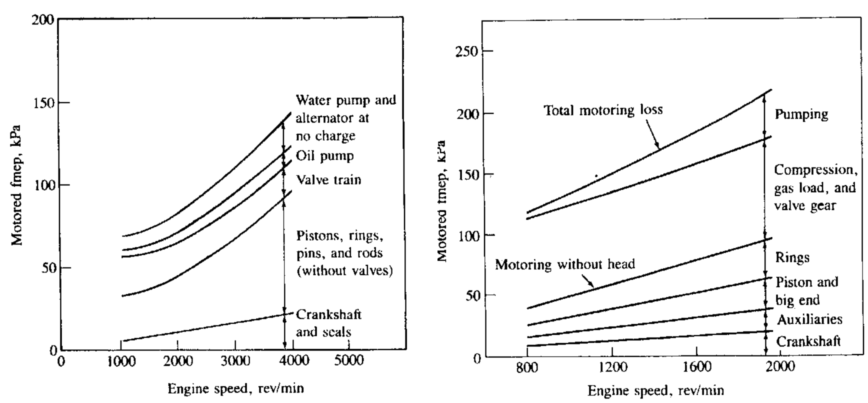
Increasing load,
Decreasing speed

Decreasing load,
increasing speed

μ = lubricant viscosity
N = shaft rotation speed
σ = loading force / area

Fig 13.3

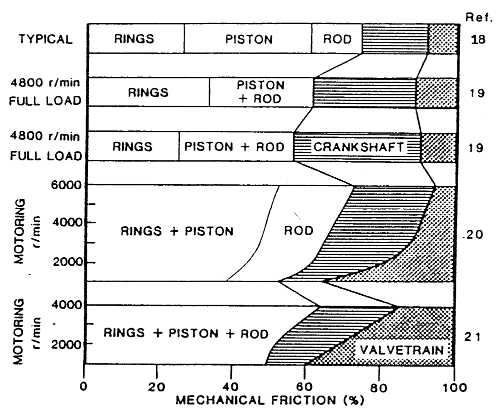
Motoring break-down analysis



(a) (b)

Fig. 13-14
Motored fmep 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



F.A. Martin, "Friction in Internal Combustion Engines," I.Mech.E. Paper C67/85, Combustion Engines – Friction and Wear, pp.1-17,1985.

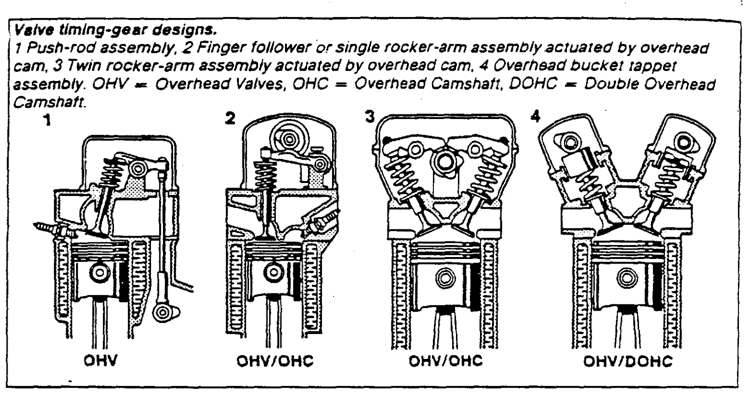
T. Hisatomi and H. Iida, "Nissan Motor Company's New 2.0 L. Four-cylinder Gasoline Engine," SAE Trans. Vol. 91, pp. 369-383, 1982; 1st engine.

2nd engine.

M. Hoshi, "Reducing Friction Losses in Automobile Engines," Tribology International, Vol. 17, pp 185-189, Aug. 1984.

J.T. Kovach, E.A. Tsakiris, and L.T. Wong, "Engine Friction Reduction for Improved Fuel Economy," SAE Trans. Vol. 91, pp. 1-13, 1982

Valve train friction



From Bosch Handbook

Valve train friction depends on:

- **Total contact areas**
- **Stress on contact areas**
  - ➢**Spring and inertia loads**

Low friction valve train

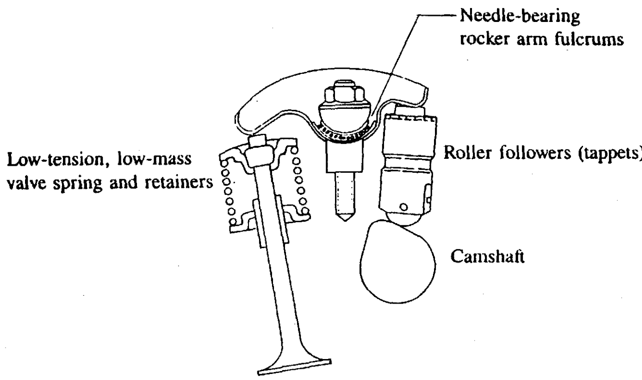
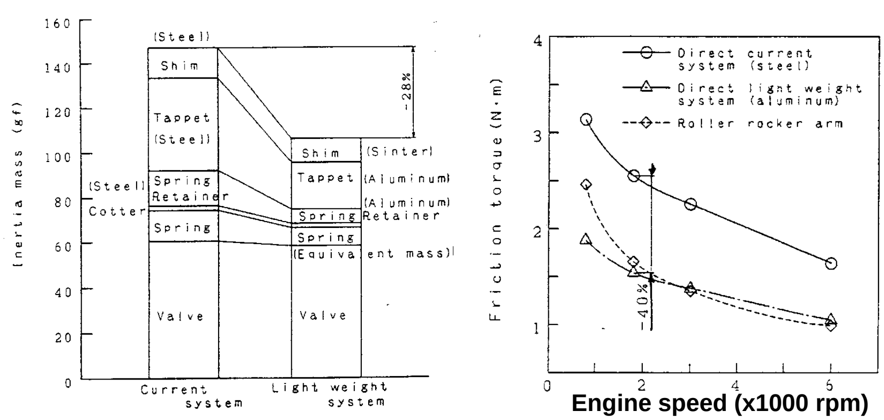


FIGURE 13-25
Low friction valve train.[22]

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

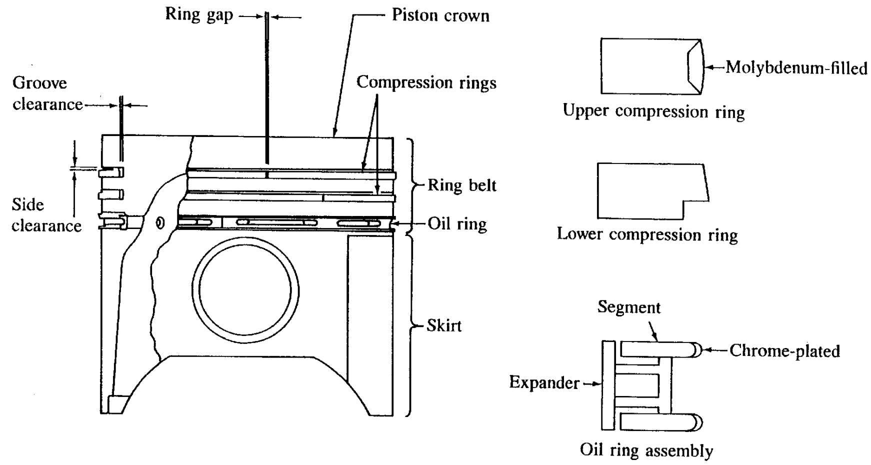


FIGURE 13-17
Construction and nomenclature of typical piston and ring assembly.[10]

Piston ring-pack dimensions

Vertical Motion:

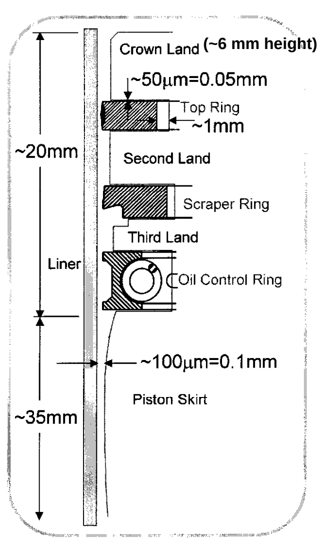
- Stroke ~ 100mm
- Mean Piston Speed
  ~ 10m/s ~ 20 mph
- Peak Piston Acceleration
  ~ 10,000m/s^2 ~ 1000 g

Lateral Motion:

- Displacement ~ 100μm
- Velocity ~ 10-100 mm/s

Cylinder Liner:

- Liner Roughness ~ 0.1 μm
- Bore Distortion
  ~ 100 μm ~ 0.1mm



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
- Rougness ~ 0.01μm
- Thermal deformation ~ 100 μm
- Mechanical deformation ~ 100 μm

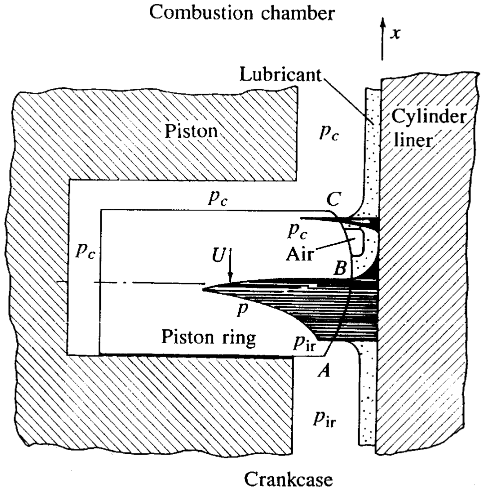
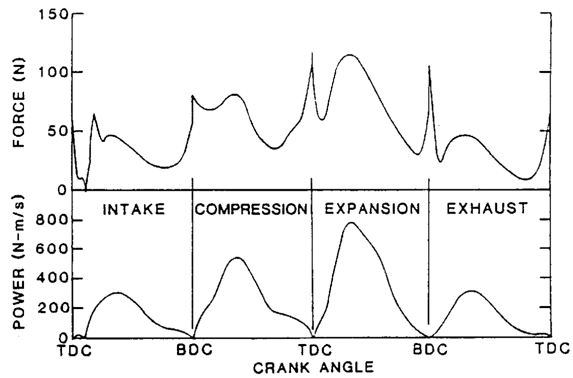


FIGURE 13-18
Schematic of pressure distribution in the lubricating oil film and around a compression ring during expansion stroke. Pressure profile in the oil film indicated by horizontal shading.[3]

Hydrodynamic lubrication of the piston ring

Friction force and associated power loss



Piston slap

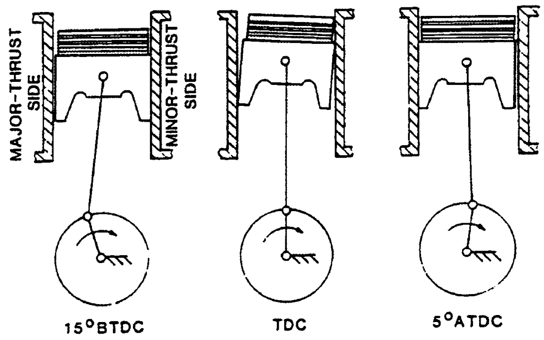


FIGURE 17
Piston motion near TDC firing with piston-pin
Offset toward major-thrust side. (by 1-2% of bore)

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

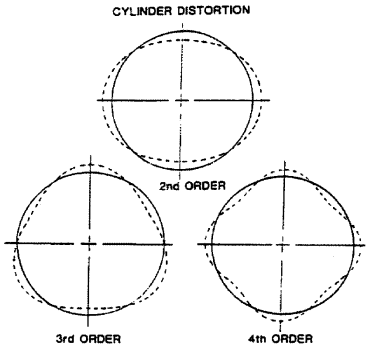


FIGURE 11
Three orders of bore distortion.

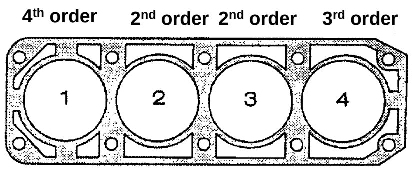
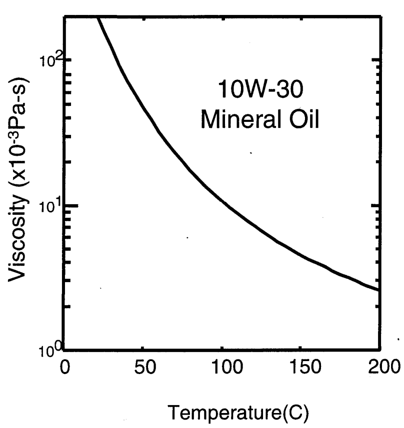


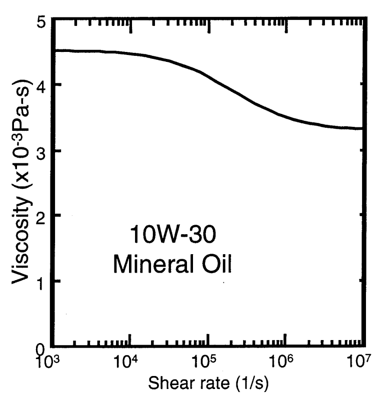
FIGURE 12
Top deck of hypothetical engine.

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



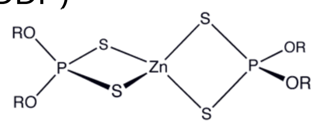


(From Linna et.al, SAE Paper 972892)

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



(R = alkyl)

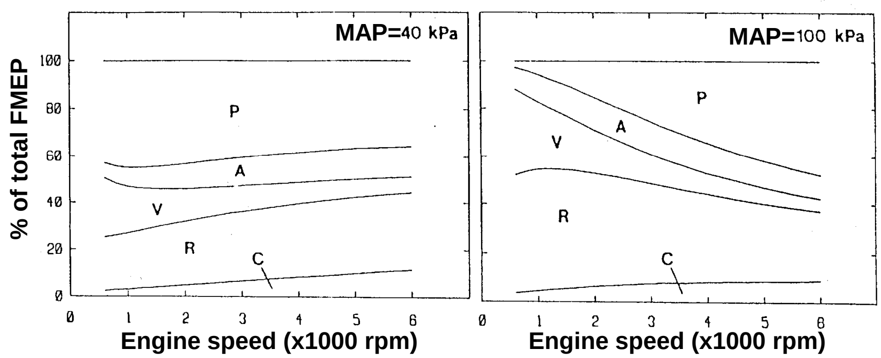
Modeling of engine friction

- Overall engine friction model:
  - tfmep (bar) = fn (rpm, V_d, ν, 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

$$\text{tfmep} = \sum (\text{fmep})_{\text{components}}$$

With detailed modeling of component friction as a function of rpm, load, …

FMEP distribution



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

SAE 890836