2.61 Internal Combustion Engines
Spring 2008

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)

Engine Friction

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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.

Pumping loss

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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

Sliding friction mechanism

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Energy dissipation processes:

- **Detaching chemical binding between surfaces**
- **Breakage of mechanical interference (wear)**

Bearing Lubrication

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Stribeck Diagram for journal bearing

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Motoring break-down analysis

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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

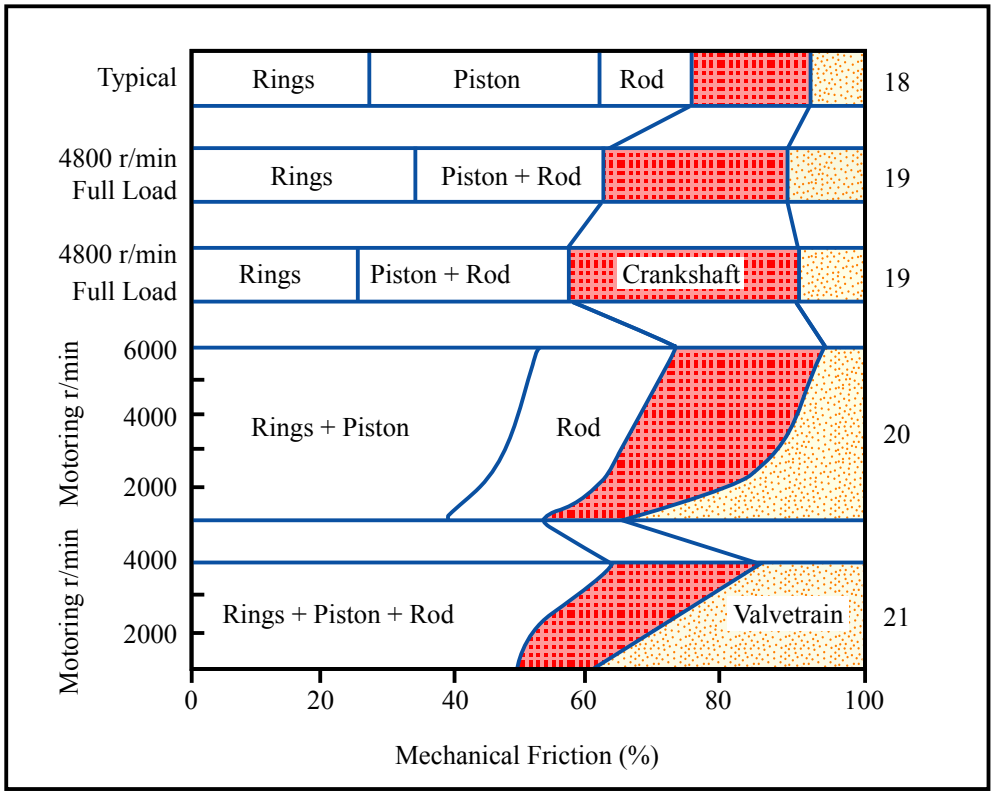

Figure by MIT OpenCourseWare.

1 **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

Image removed due to copyright restrictions. Please see illustrations of "Valve Timing-gear Designs." In the *Bosch Automotive Handbook*. London, England: John Wiley & Sons, 2004.

Valve train friction depends on:

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

Low friction valve train

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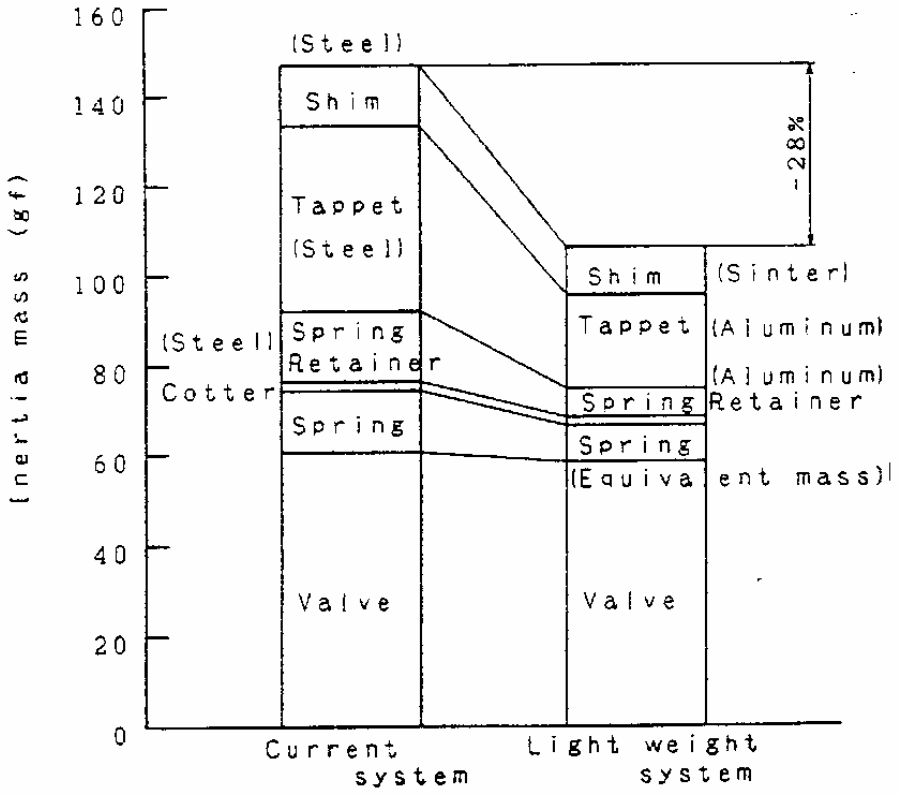
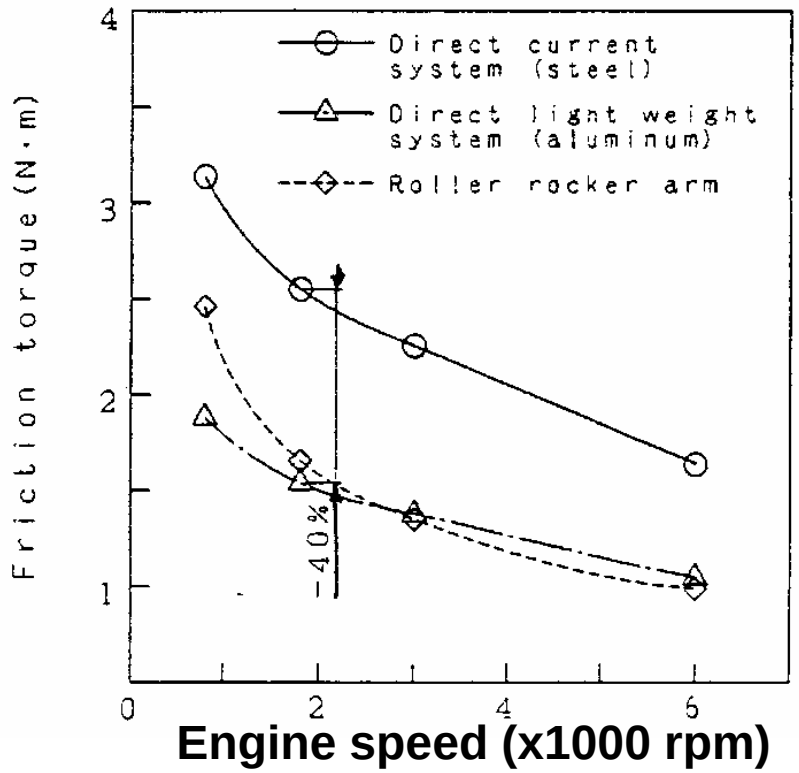
Valve train friction reduction





"Friction loss reduction by new lighter valve train system,"
JSAE Review 18 (1977), Fukuoka, Hara, Mori, and Ohtsubo

Piston ring pack

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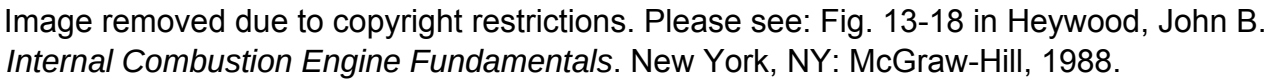
Hydrodynamic lubrication of the piston ring



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Friction force and associated power loss

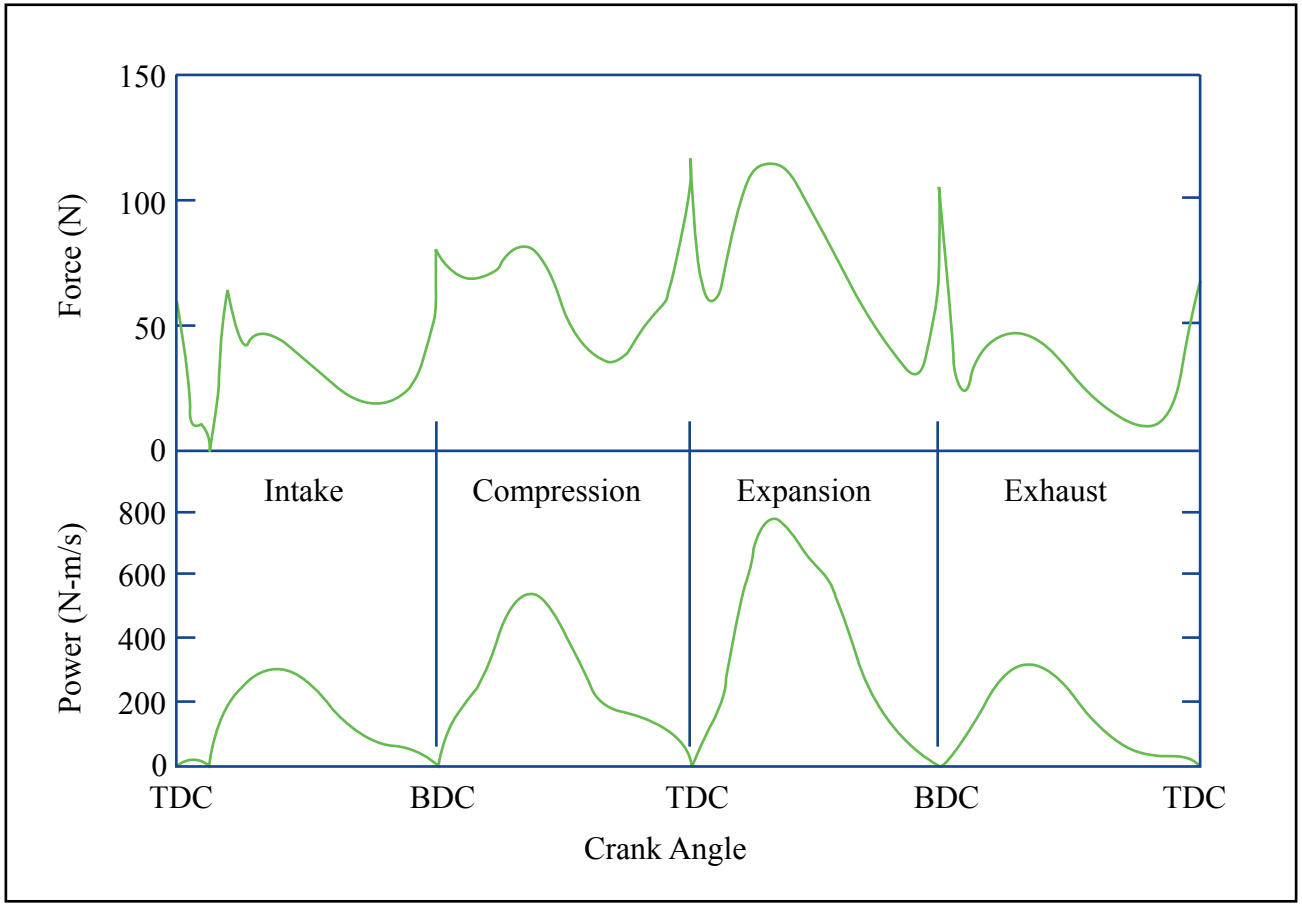
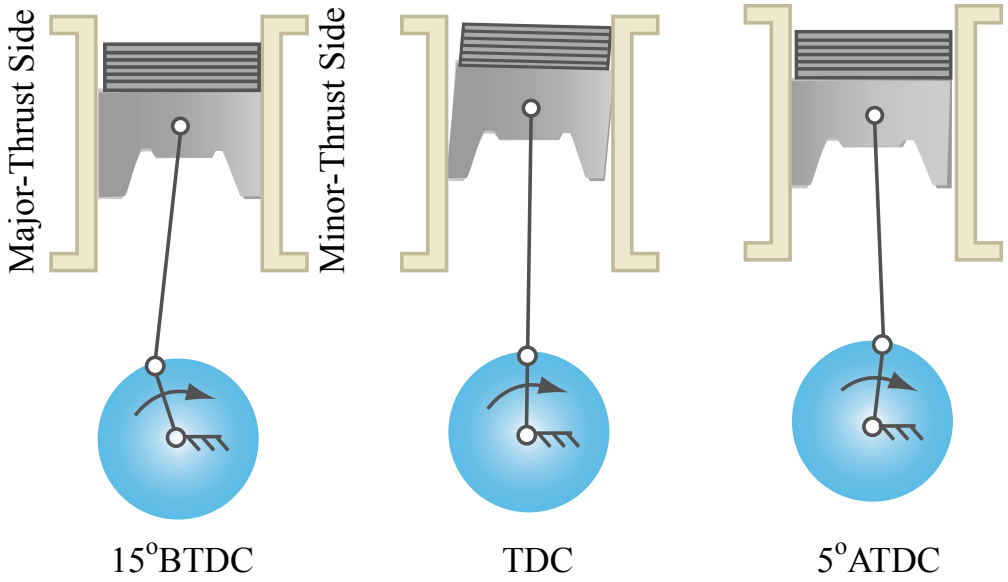


Figure by MIT OpenCourseWare.

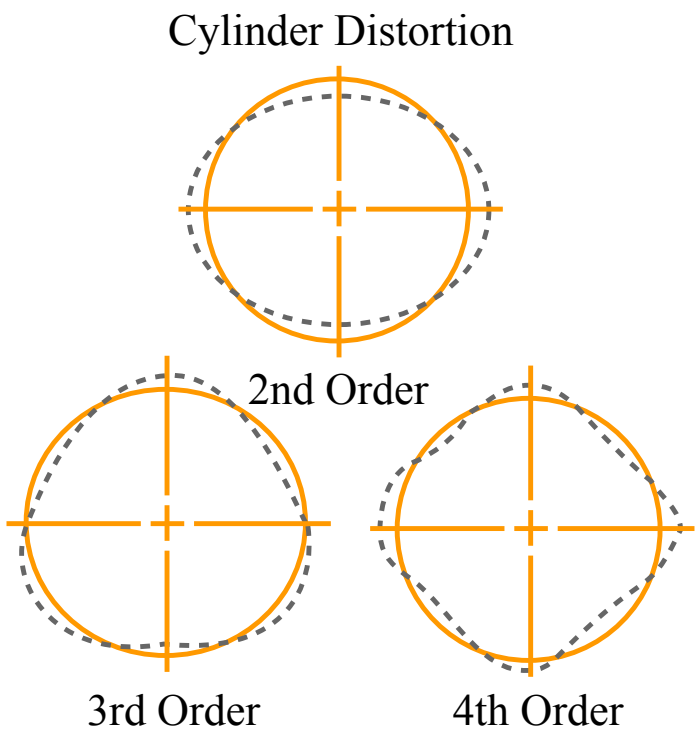
Piston slap



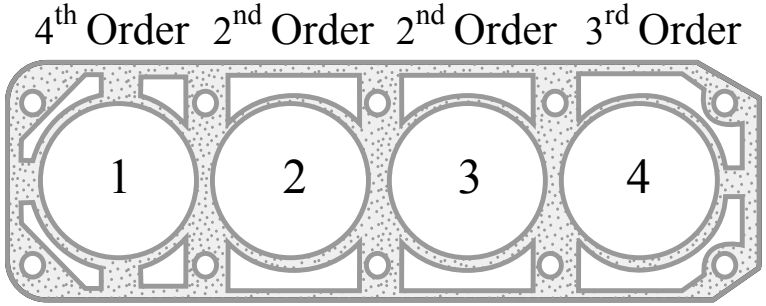
Piston motion near TDC firing with piston-pin offset toward major-thrust side.

Figure by MIT OpenCourseWare.

Bore distortion



Three orders of bore distortion.



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

Image removed due to copyright restrictions. Please see: Linna, Jan-Roger, et al. "Contribution of Oil Layer Mechanism to the Hydrocarbon Emissions from Spark-ignition Engines." *SAE Journal of Fuels and Lubricants* 106 (October 1997): 972892.

Modeling of engine friction

- Overall engine friction model:
  - tfmep (bar) = fn (rpm, V_d, ν, B, S, ….)
  - See text, ch. 13, ref.6; SAE 900223, …)

- Detailed model

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

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

FMEP distribution

Image removed due to copyright restrictions. Please see: Patton, Kenneth J., et al. "Development and Evaluation of a Friction Model for Spark-ignition Engines." *SAE Journal of Engines* 98 (February 1989): 890836.

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