

## 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 → MEP

- $tfmep = pmep + rfmep + amep$

Net output of engine

- $bmep = imep(g) - tfmep$

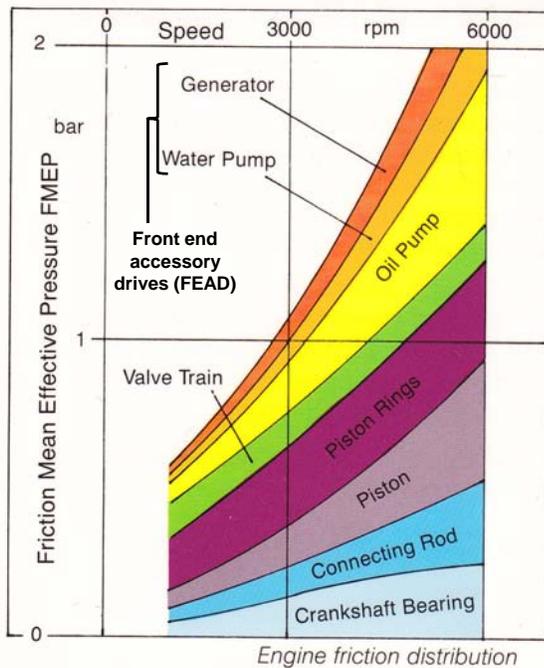
Mechanical efficiency

- $\eta_m = bmep / imep(g)$

## 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)

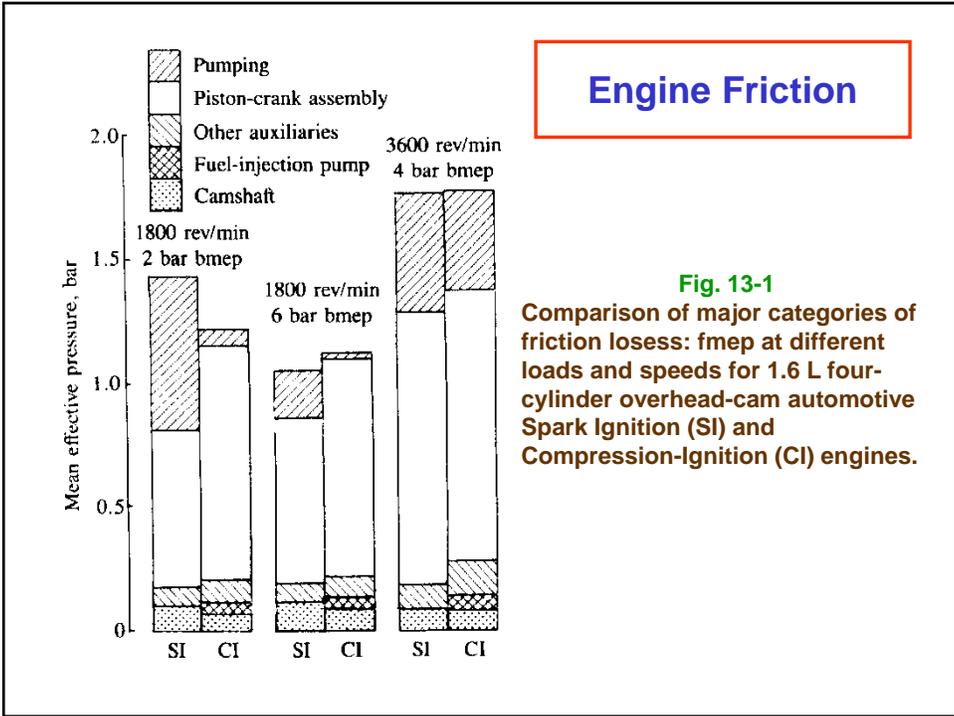
\*Have to be careful to avoid double-counting. The engine coolant and oil flow losses are provided for by the oil and water pump. The nature of the loss is a pumping loss though.



## SI engine friction

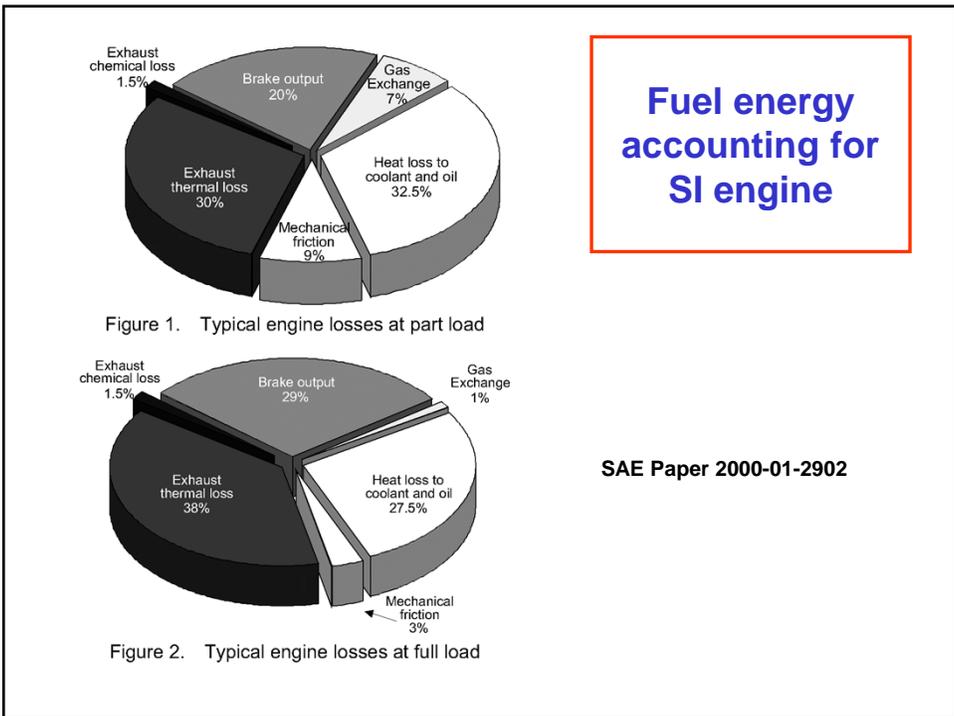
(excluding pumping loss)

Source: FEV Brochure



**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.**

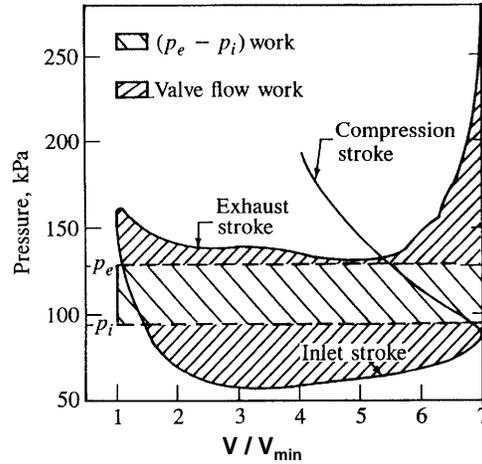
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SAE Paper 2000-01-2902

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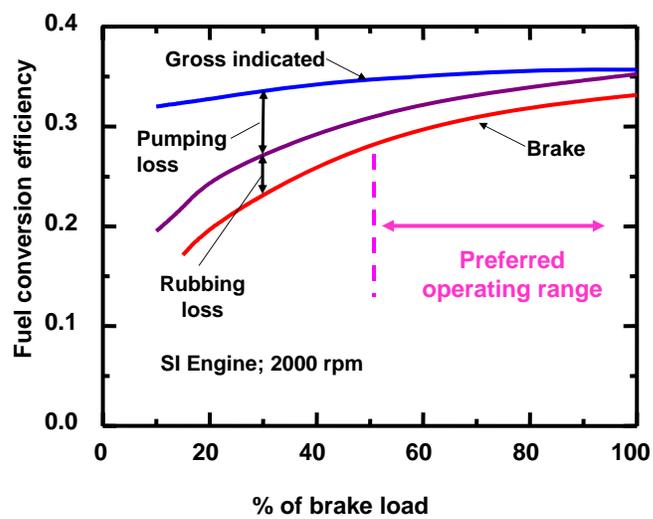
## Pumping loss



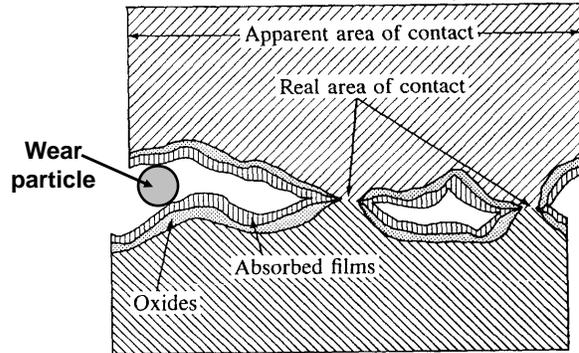
**Fig. 13-15 Pumping loop diagram for SI engine under firing conditions, showing throttling work  $V_d(p_e - p_i)$ , and valve flow work**

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## SI Engine losses



## Sliding friction mechanism



Energy dissipation processes:

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

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## Bearing Lubrication

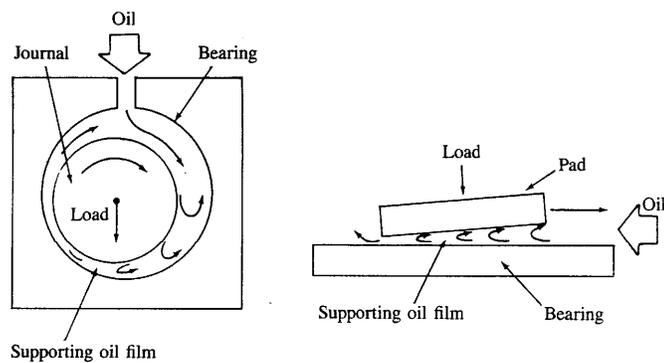
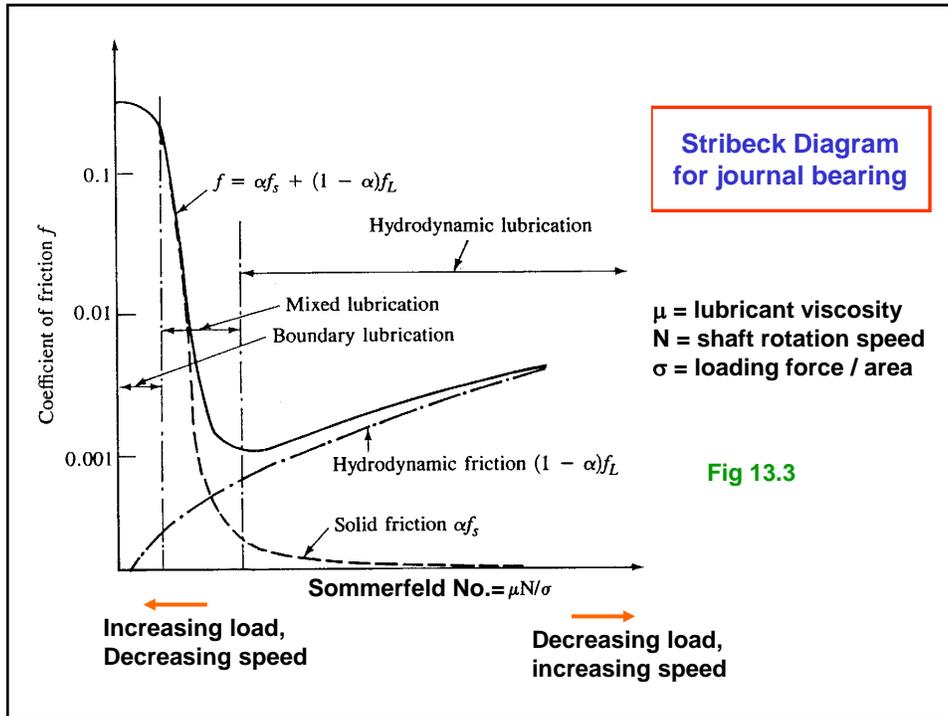
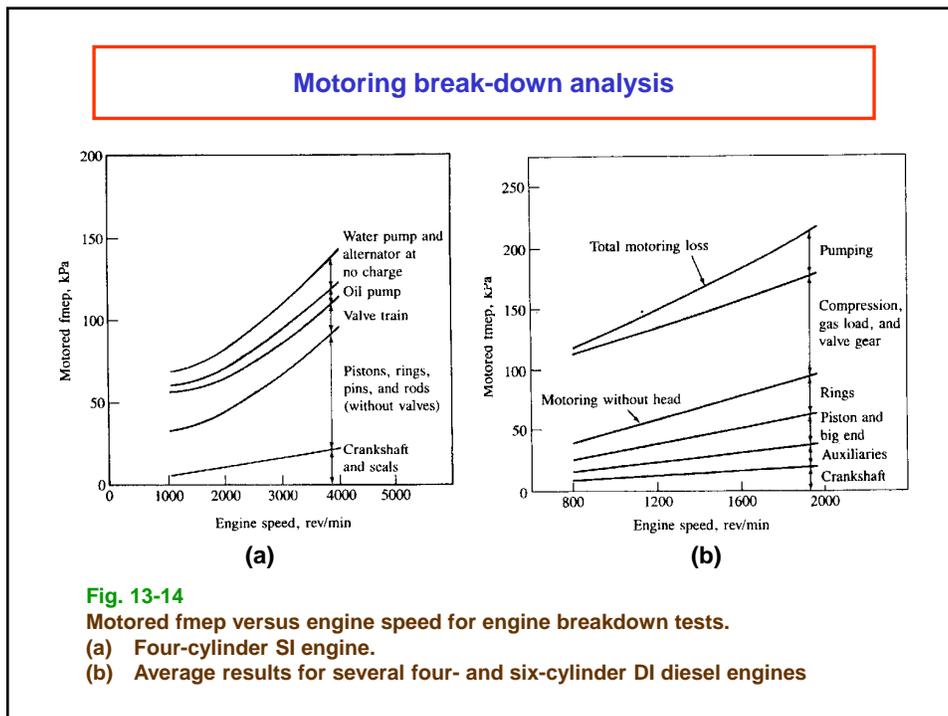


FIGURE 13-2  
Schematic of a lubricated journal and a slider bearing.

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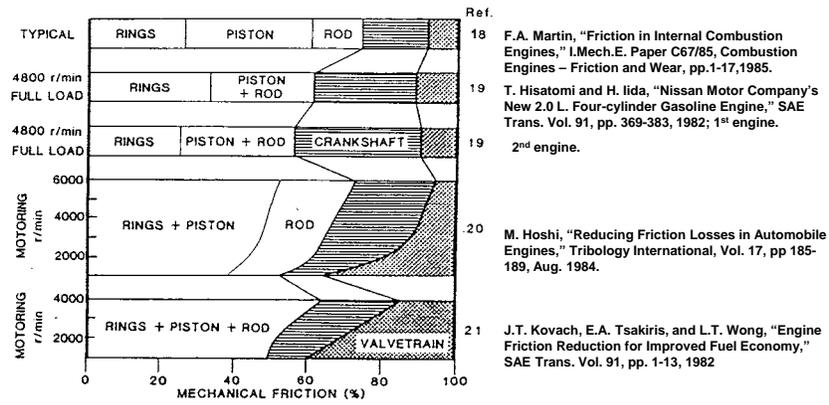


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## Breakdown of engine mechanical friction

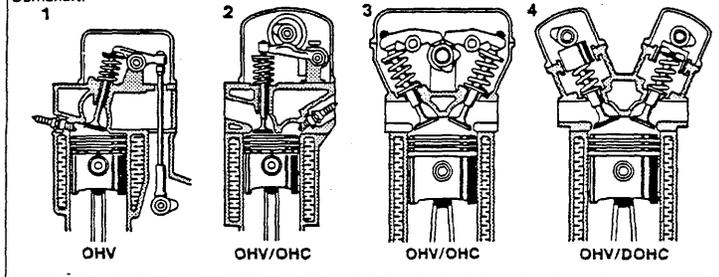


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## Valve train friction

### Valve timing-gear designs.

1 Push-rod assembly, 2 Finger follower or single rocker-arm assembly actuated by overhead cam, 3 Twin rocker-arm assembly actuated by overhead cam, 4 Overhead bucket tappet assembly. OHV = Overhead Valves, OHC = Overhead Camshaft, DOHC = Double Overhead Camshaft.



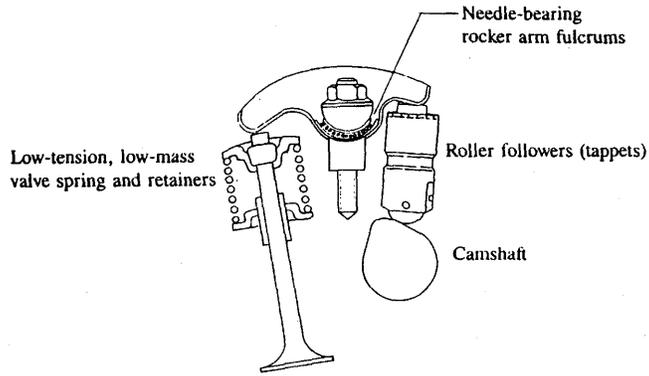
From  
Bosch  
Handbook

Valve train friction depends on:

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

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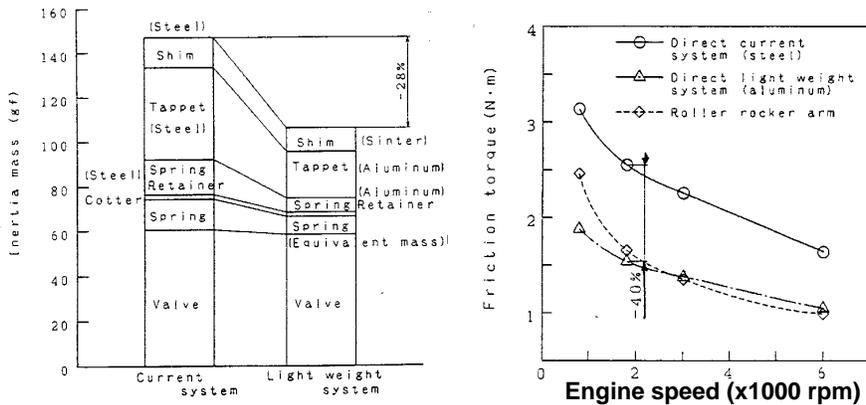
## Low friction valve train



**FIGURE 13-25**  
Low friction valve train.<sup>22</sup>

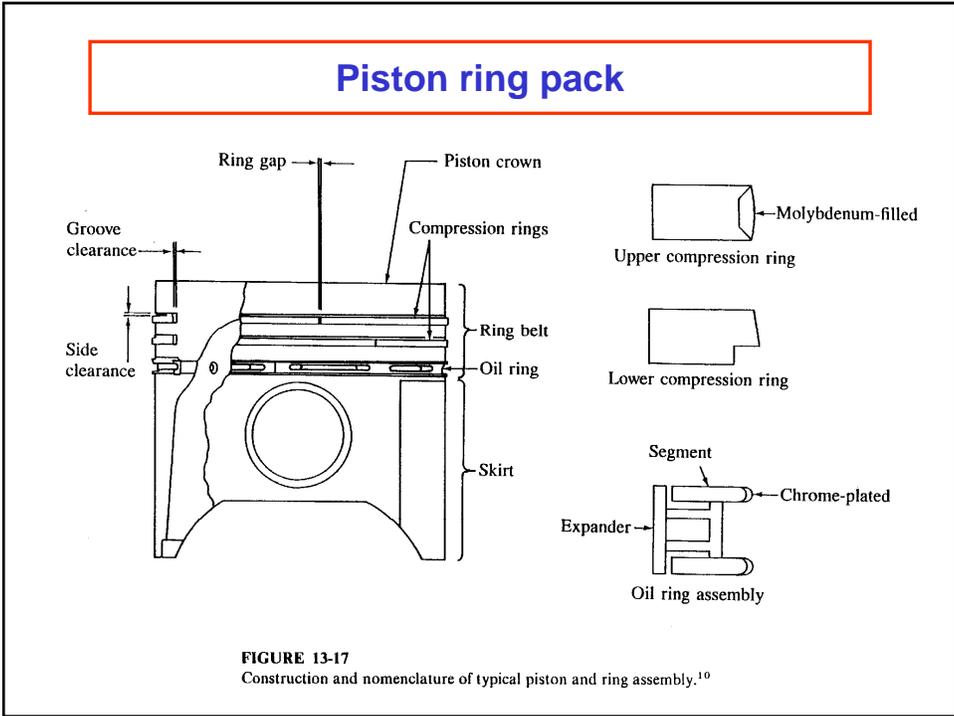
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## Valve train friction reduction

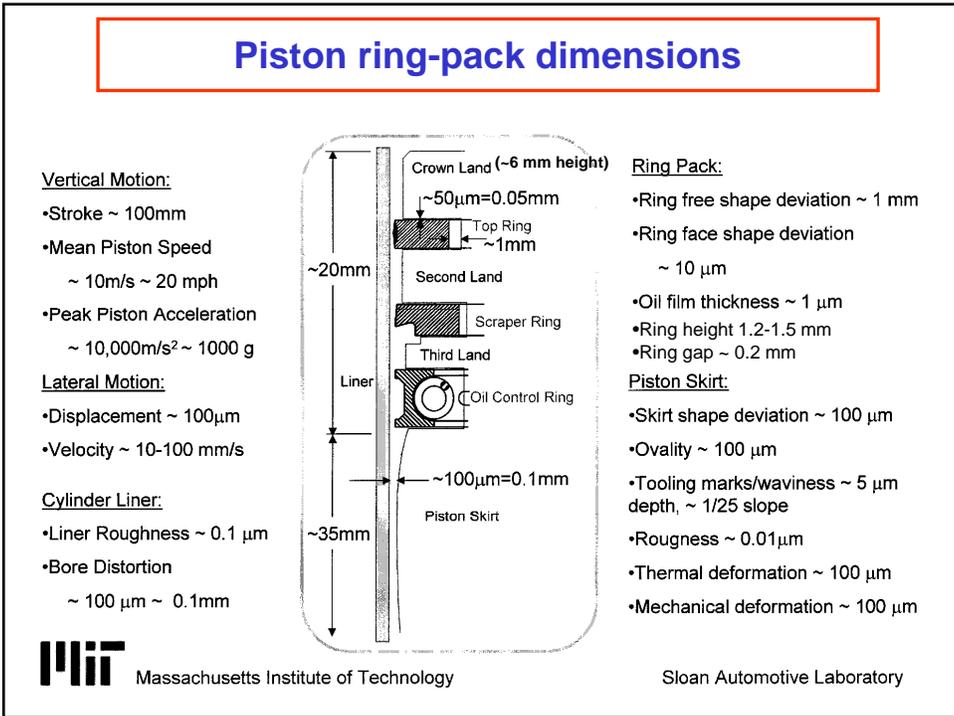


**“Friction loss reduction by new lighter valve train system,”  
JSAE Review 18 (1977), Fukuoka, Hara, Mori, and Ohtsubo**

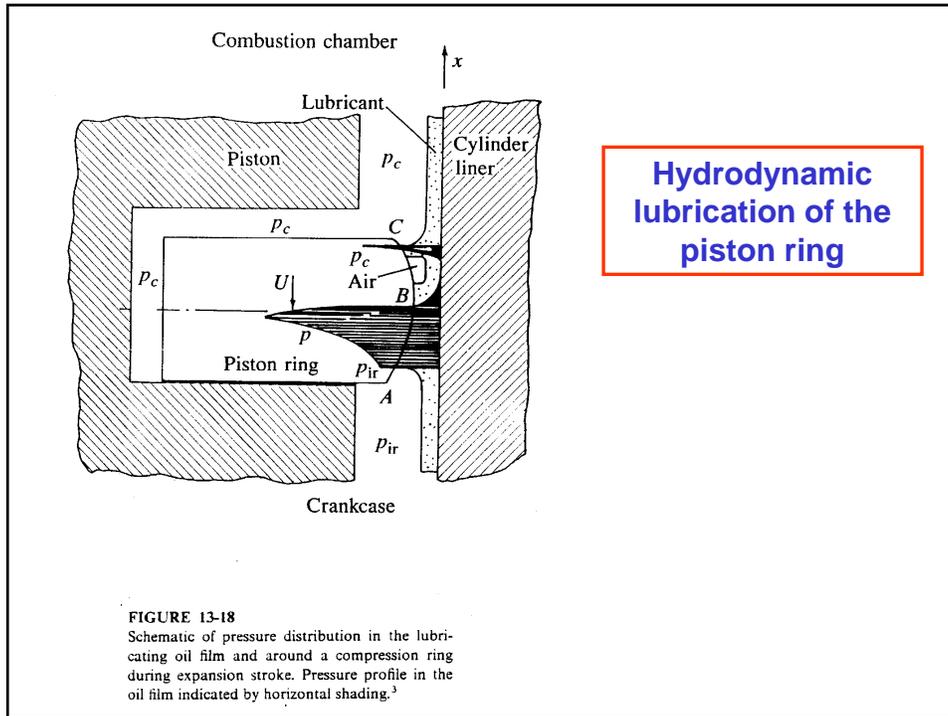
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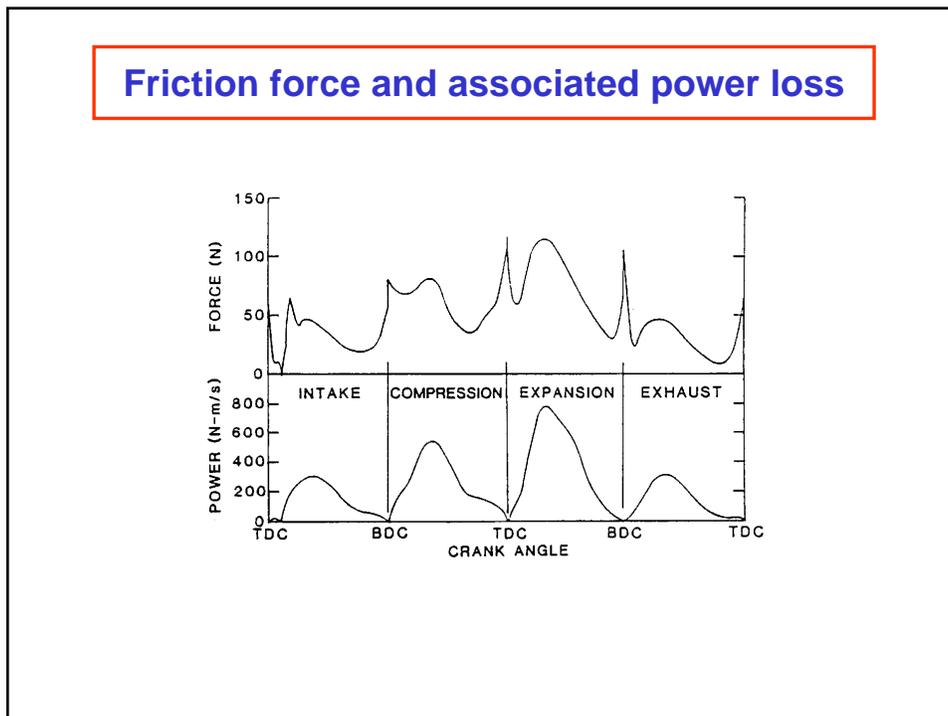
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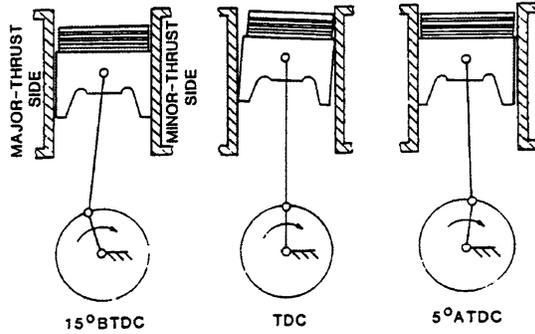
Source: MIT Sloan Automotive Laboratory.



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## Piston slap



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

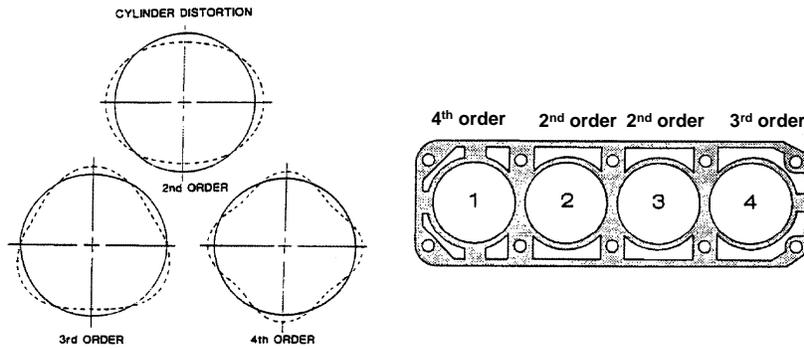
Change timing (earlier) of transition so that the cylinder pressure at transition is lower – less force to accelerate piston

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

Also the “slap” force is lower

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## Bore distortion



**FIGURE 11**  
Three orders of bore distortion.

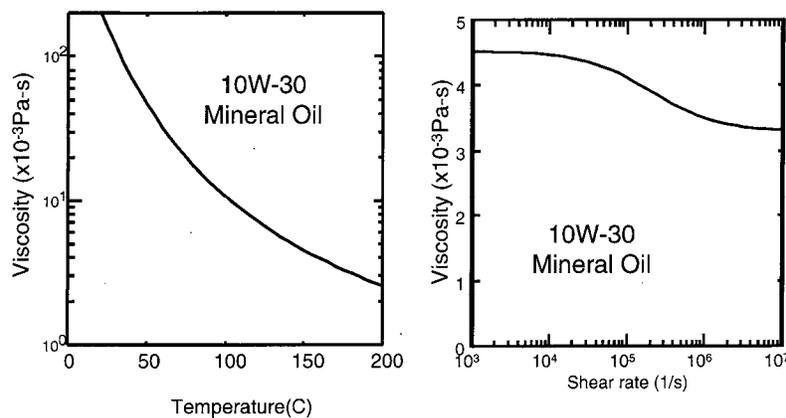
**FIGURE 12**  
Top deck of hypothetical engine.

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## 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

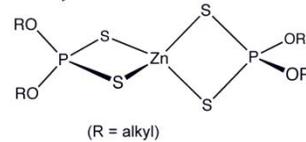


(From Linna et.al, SAE Paper 972892)

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 dialkyldithiophosphate (ZDDP)
  - Formation of anti-wear film



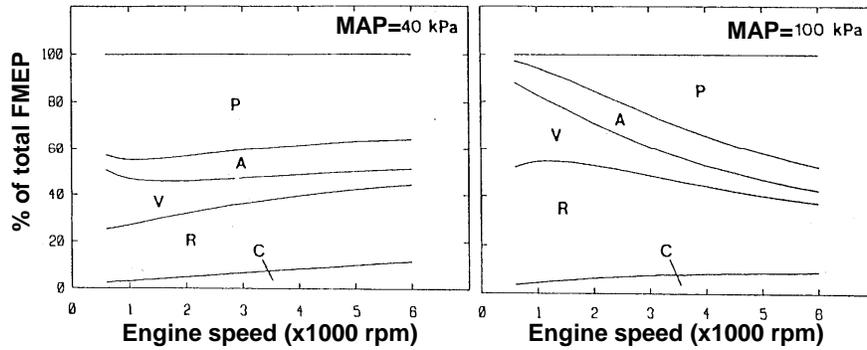
## Modeling of engine friction

- Overall engine friction model:
  - $tfmep$  (bar) =  $f_n$  (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

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

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

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