Lecture 4

ENGINE POWER

INTERNAL COMBUSTION ENGINES

By

A Lecturer

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2.2. ENGINE WORK

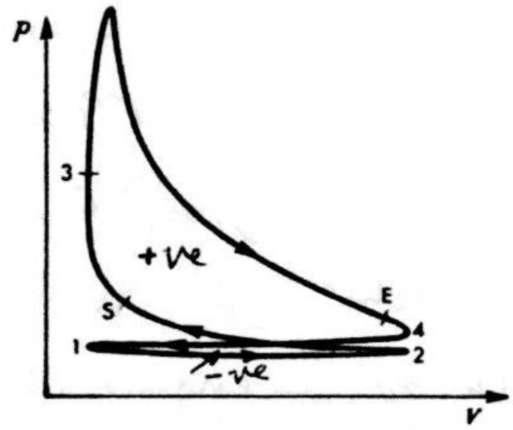

Fig. 2.2 Indicator diagram of SI engine

Work is the output of any heat engine and a reciprocating IC engine this work is generated by the gases in the combustion chamber of the cylinder.

$$W = \int F dx = \int P A_p dx = \int P dV$$

Where : P=pressure in combustion chamber

A_p = area against which the pressure acts

x = distance the piston moves

Per unit mass: $w = \frac{W}{m}$ $v = \frac{V}{m}$ kJ/kg

indicated work (w_i): the work inside the combustion chamber

brake work (w_b): the actual work available at the crankshaft where it less than indicated work

$$w_b = w_i - w_f$$

Where : w_f = specific work lost due to friction and parasitic loads.

The mechanical efficiency

The mechanical efficiency is the ratio of brake work at crankshaft to indicated work in the combustion chamber, it have range of 75% to 95% at high modern automobile operating at wide- open throttle.

$$\boldsymbol{\eta_m} = \frac{w_b}{w_i} = \frac{\boldsymbol{W_b}}{\boldsymbol{W_i}}$$

2.3 MEAN EFFECTIVE PRESSURE

Mean effective pressure is (mep) is define by:

$$w = (\text{mep})\Delta v \tag{2-28}$$

or:

$$\text{mep} = w/\Delta v = W/V_d \tag{2-29}$$

$$\Delta v = v_{\text{BDC}} - v_{\text{TDC}} \tag{2-30}$$

where: W = work of one cycle
w = specific work of one cycle
V_d = displacement volume

Mean effective pressure is a good parameter to compare engines for design or output because it is independent of engine size and/or speed. If torque is used for engine comparison, a larger engine will always look better. If power is used as the comparison, speed becomes very important.

Various mean effective pressures can be defined by using different work terms in Eq. (2-29). If brake work is used, **brake mean effective pressure** is obtained:

$$\text{bmep} = w_b/\Delta v \tag{2-31}$$

Indicated work gives **indicated mean effective pressure**:

$$\text{imep} = w_i/\Delta v \tag{2-32}$$

The imep can further be divided into gross indicated mean effective pressure and net indicated mean effective pressure:

$$(\text{imep})_{\text{gross}} = (w_i)_{\text{gross}} / \Delta v \qquad (2\text{-}33)$$

$$(\text{imep})_{\text{net}} = (w_i)_{\text{net}} / \Delta v \qquad (2\text{-}34)$$

Pump mean effective pressure (which can have negative values):

$$\text{pmep} = w_{\text{pump}} / \Delta v \qquad (2\text{-}35)$$

Friction mean effective pressure:

$$\text{fmep} = w_f / \Delta v \qquad (2\text{-}36)$$

The following equations relate some of the previous definitions:

$$\left.\begin{aligned} \text{nmep} &= \text{gmep} + \text{pmep} && \text{(a)} \\ \text{bmep} &= \text{nmep} - \text{fmep} && \text{(b)} \\ \text{bmep} &= \eta_m \text{imep} && \text{(c)} \\ \text{bmep} &= \text{imep} - \text{fmep} && \text{(d)} \end{aligned}\right\} \quad (2\text{-}37)$$

where: nmep = net mean effective pressure
η_m = mechanical efficiency of engine

Typical maximum values of bmep for naturally aspirated SI engines are in the range of 850 to 1050 kPa (120 to 150 psi). For CI engines, typical maximum values are 700 to 900 kPa (100 to 130 psi) for naturally aspirated engines and 1000 to 1200 kPa (145 to 175 psi) for turbocharged engines [58].

2-4 TORQUE AND POWER

Torque is a good indicator of an engine's ability to do work. It is defined as force acting at a moment distance and has units of N-m or lbf-ft. Torque τ is related to work by:

$$2\pi\tau = W_b = (\text{bmep}) V_d / n \qquad (2\text{-}38)$$

where: W_b = brake work of one revolution
V_d = displacement volume
n = number of revolutions per cycle

For a two-stroke cycle engine with one cycle for each revolution:

$$2\pi\tau = W_b = (\text{bmep}) V_d \qquad (2\text{-}39)$$

$$\tau = (\text{bmep}) V_d / 2\pi \qquad \text{two-stroke cycle} \qquad (2\text{-}40)$$

For a four-stroke cycle engine which takes two revolutions per cycle:

$$\tau = (\text{bmep}) V_d / 4\pi \qquad \text{four-stroke cycle} \qquad (2\text{-}41)$$

Power

Power is defined as the rate of work of the engine. If n = number of revolutions per cycle, and N = *engine speed*, then:

$$\dot{W} = WN/n \tag{2-42}$$

$$\dot{W} = 2\pi N\tau \tag{2-43}$$

$$\dot{W} = (1/2n)(\text{mep})A_p\overline{U}_p \tag{2-44}$$

$$\dot{W} = (\text{mep})A_p\overline{U}_p/4 \quad \text{four-stroke cycle} \tag{2-45}$$

$$\dot{W} = (\text{mep})A_p\overline{U}_p/2 \quad \text{two-stroke cycle} \tag{2-46}$$

where: W = work per cycle
A_p = piston face area of all pistons
$\overline{U}_p$ = average piston speed

Depending upon which definition of work or mep is used in Eqs. (2-42)–(2-46), power can be defined as brake power, net indicated power, gross indicated power, pumping power, and even friction power. Also:

$$\dot{W}_b = \eta_m \dot{W}_i \tag{2-47}$$

$$(\dot{W}_i)_{\text{net}} = (\dot{W}_i)_{\text{gross}} - (\dot{W}_i)_{\text{pump}} \tag{2-48}$$

$$\dot{W}_b = \dot{W}_i - \dot{W}_f \tag{2-49}$$

where η_m is the mechanical efficiency of the engine.

Power is normally measured in kW, but horsepower (hp) is still common.

$$1 \text{ hp} = 0.7457 \text{ kW} = 2545 \text{ BTU/hr} = 550 \text{ ft-lbf/sec}$$
$$1 \text{ kW} = 1.341 \text{ hp} \tag{2-50}$$

Other ways which are sometimes used to classify engines are shown in Eqs. (2-51)-(2-54).

specific power	$SP = \dot{W}_b/A_p$	(2-51)
output per displacement	$OPD = \dot{W}_b/V_d$	(2-52)
specific volume	$SV = V_d/\dot{W}_b$	(2-53)
specific weight	$SW = (\text{engine weight})/\dot{W}_b$	(2-54)

where: $\dot{W}_b$ = brake power
A_p = piston face area of all pistons
V_d = displacement volume

EXAMPLE PROBLEM 2-2

3L V6 SI engine operates on 4-strock, the clearance volume of each cylinder is 59 cm^2 . Bore cylinder is 8.6 cm , the average piston speed is 10.32 m/s. if this engine connected to a dynamometer which gives a brake output torque reading of 205 N-m at 3600 RPM. At this speed air enters the cylinders at 85 kPa and 60°C, and the mechanical efficiency of the engine is 85%.

Calculate :

1. brake power
2. indicated power
3. brake mean effective pressure
4. indicated mean effective pressure
5. friction mean effective pressure
6. power lost to friction
7. brake work per unit mass of gas in the cylinder
8. brake specific power
9. brake output per displacement
10. engine specific volume

1) Using Eq. (2-43) to find brake power:

$$\dot{W}_b = 2\pi N\tau = (2\pi \text{ radians/rev})(3600/60 \text{ rev/sec})(205 \text{ N-m})$$
$$= 77{,}300 \text{ N-m/sec} = \underline{77.3 \text{ kW} = 104 \text{ hp}}$$

2) Using Eq. (2-47) to find indicated power:

$$\dot{W}_i = \dot{W}_b / \eta_m = (77.3 \text{ kW})/(0.85) = \underline{90.9 \text{ kW} = 122 \text{ hp}}$$

3) Using Eq. (2-41) to find the brake mean effective pressure:

$$\text{bmep} = 4\pi\tau / V_d = (4\pi \text{ radians/cycle})(205 \text{ N-m})/(0.003 \text{ m}^3\text{/cycle})$$
$$= \underline{859{,}000 \text{ N/m}^2 = 859 \text{ kPa} = 125 \text{ psia}}$$

4) Equation (2-37c) gives indicated mean effective pressure:

$$\text{imep} = \text{bmep}/\eta_m = (859\ \text{kPa})/(0.85) = \underline{1010\ \text{kPa} = 146\ \text{psia}}$$

5) Equation (2-37d) is used to calculate friction mean effective pressure:

$$\text{fmep} = \text{imep} - \text{bmep} = 1010 - 859 = \underline{151\ \text{kPa} = 22\ \text{psia}}$$

6) Equations (2-15) and (2-44) are used to find friction power lost:

$$A_p = (\pi/4)B^2 = (\pi/4)(0.086\ \text{m})^2 = 0.00581\ \text{m}^2 \text{ for one cylinder}$$

$$\dot{W}_f = (1/2n)(\text{fmep})A_p\overline{U}_p$$

$$= (1/4)(151\ \text{kPa})(0.00581\ \text{m}^2/\text{cyl})(10.32\ \text{m/sec})(6\ \text{cyl})$$

$$= \underline{13.6\ \text{kW} = 18\ \text{hp}}$$

Or, it can be obtained from Eq. (2-49):

$$\dot{W}_f = \dot{W}_i - \dot{W}_b = 90.9 - 77.3 = 13.6\ \text{kW}$$

7) First brake work is found for one cylinder for one cycle using Eq. (2-29):

$$W_b = (\text{bmep})V_d = (859\ \text{kPa})(0.0005\ \text{m}^3) = 0.43\ \text{kJ}$$

It can be assumed the gas entering the cylinders at BDC is air:

$$m_a = PV_{\text{BDC}}/RT = P(V_d + V_c)/RT$$

$$= (85\ \text{kPa})(0.0005 + 0.000059)\text{m}^3/(0.287\ \text{kJ/kg-K})(333\ \text{K})$$

$$= 0.00050\ \text{kg}$$

Brake specific work per unit mass:

$$w_b = W_b/m_a = (0.43\ \text{kJ})/(0.00050\ \text{kg}) = \underline{860\ \text{kJ/kg} = 370\ \text{BTU/lbm}}$$

8) Equation (2-51) gives brake specific power:

$$\text{BSP} = \dot{W}_b/A_p = (77.3\ \text{kW})/[(\pi/4)(0.086\ \text{m})^2(6\ \text{cylinders})]$$

$$= \underline{2220\ \text{kW/m}^2 = 0.2220\ \text{kW/cm}^2 = 1.92\ \text{hp/in.}^2}$$

9) Equation (2-52) gives brake output per displacement:

$$\text{BOPD} = \dot{W}_b/V_d = (77.3\ \text{kW})/(3\ \text{L})$$

$$= \underline{25.8\ \text{kW/L} = 35\ \text{hp/L} = 0.567\ \text{hp/in.}^3}$$

10) Equation (2-53) gives engine specific volume:

$$\text{BSV} = V_d/\dot{W}_b = 1/\text{BOPD} = 1/25.8$$

$$= \underline{0.0388\ \text{L/kW} = 0.0286\ \text{L/hp} = 1.76\ \text{in.}^3/\text{hp}}$$

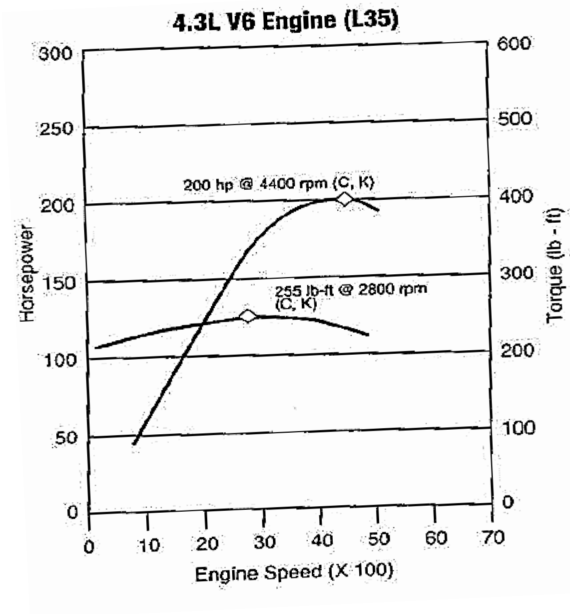

Figure 2-8 Power and torque curves of General Motors L35 Vortec V6 engine shown in Fig. 2-7. The engine has a compression ratio of 9.2:1 and a listed maximum speed of 5600 RPM. Maximum rated power is 200 hp (149 kW) at 4400 RPM and maximum rated torque is 255 lbf-ft (346 N-m) at 2800 RPM. Copyright General Motors Corp., used with permission.

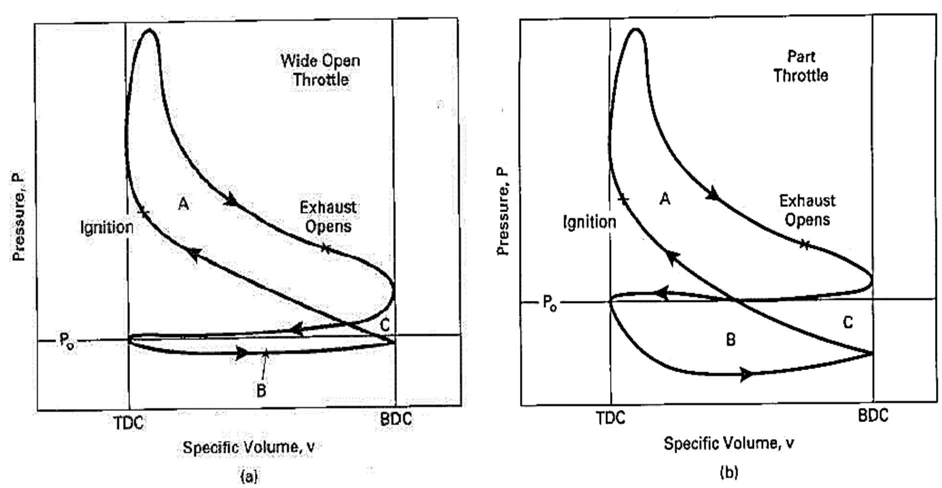

Figure 2-9 Four-stroke cycle of typical SI engine plotted on P-v coordinates at (a) wide open throttle, and (b) part throttle. The upper loop consists of the compression stroke and power stroke and the area represents gross indicated work. The lower loop represents negative work of the intake stroke and exhaust stroke. This is called indicated pump work.

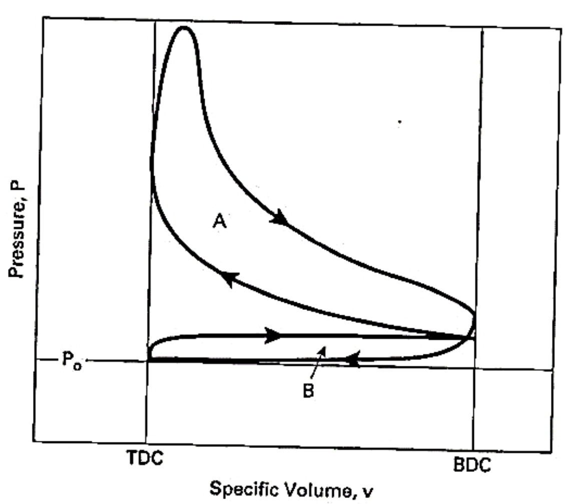

Figure 2-10 Four-stroke cycle of a SI engine equipped with a supercharger or turbocharger, plotted on P-v coordinates. For this cycle intake pressure is greater than exhaust pressure and the pump work loop represents positive work.