Politechnika Wrocławska

Combustion Engines

Engine characteristics

Basic parameters describing combustion engine

- Geometrical features
- Rotational speed
- Torque
- Power
- Pressure
- Efficiency
- Fuel consumption

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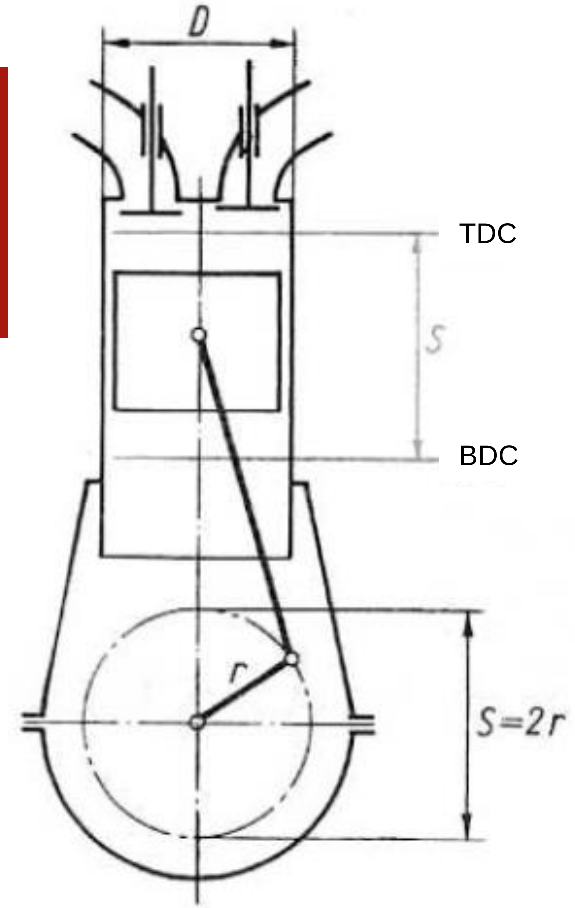
Geometrical features



Dimensions:

- **Cylinder diameter (D)**
- **Stroke (S)** –the distance covered by the piston in one stroke (between BDC and TDC)

Each stroke of the piston in a four-stroke engine is accompanied by 180° crankshaft rotation.

Cylider displacement –
the product of piston stroke and the cross-sectional area of the cylinder

$$V_s = S \cdot A_c = S \cdot \frac{\pi \cdot D^2}{4}$$

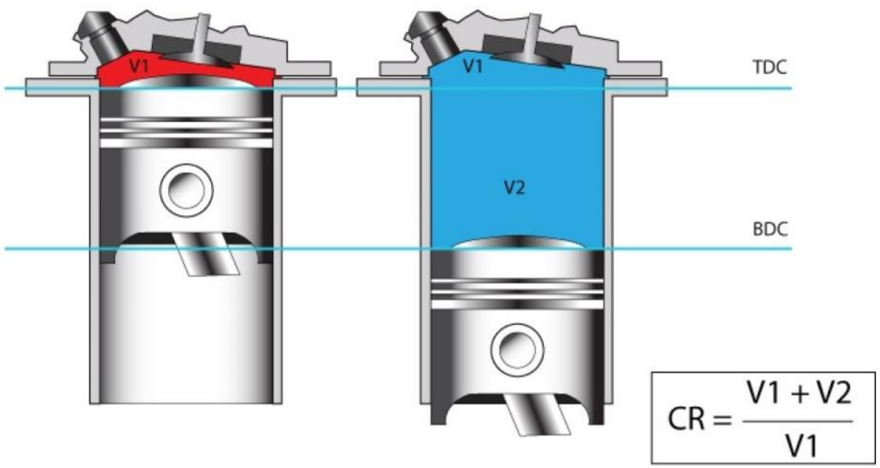
V_s – single cylinder displacement [dm^3]
S – stroke [dm]
A_c – cylinder cross-section area [dm^2]
D – cylinder diameter [dm]

Total engine displacement:

$$V_{ss} = n \cdot V_s$$

n – number of cylinders

Compression ratio



Clearance volume – cylinder space between the piston at TDC and the engine head (V_1)

SI: CR = 8 ÷ 14
CI: CR = 16 ÷ 23

Compression ratio – the ratio of the maximum volume in cylinder at piston BDC to the volume in cylinder at piston TDC

Compression ratio comparison		
Compression ratio	7	9
Maximum compression pressure	~ 1,0 MPa	~ 1,6 MPa
Maximum combustion pressure	~ 3,0 MPa	~ 4,2 MPa
Pressure at exhaust valve opening	~ 0,4 MPa	~ 0,3 MPa
Temperature at the end of compression	400 °C	500 °C

Engine rotational speed

The number of crankshaft revolutions per unit of time (*n*).
Units: RPS (SI), RPM

Engines classification regarding to *n*:

- low-speed,
- medium-speed
- **high-speed**

The smaller the cylinder capacity, the higher the rotational speed - this is due to the masses of rotating and reciprocating parts. With their increase, the inertia forces increase - the rotational speed is limited due to the strength of the assemblies.

Increasing engine speed is one way to increase engine power while keeping displacement unchanged.

Engine type	low-speed	medium-speed	high-speed
SI	$n < 1000$ RPM	$n = 1000 \div 2800$ RPM	$n > 2800$ RPM
CI	$n < 240$ RPM	$n = 240 \div 1200$ RPM	$n > 1200$ RPM

Torque

The value is measured **at the crankshaft** on the test bench (engine dyno) - M_o, Unit: Nm

Engine parameter that determines the value of the vehicle driving force.

Depends on the number of engine cylinders.

During one cycle of engine operation, the value of the torque on the crankshaft undergoes significant changes. To compensate for the differences, flywheels are used - the smaller the number of cylinders, the greater the moment of inertia of the flywheel.

Pressure

Mean Effective Pressure (MEP) can be regarded as an average pressure in the cylinder for a complete engine cycle (theoretical). By definition, mean effective pressure is the ratio between the work and engine displacement.

Indicated Mean Effective Pressure (IMEP) is the mean effective pressure calculated with indicated power (work). It can be obtained from the work calculation basing on the indicator diagram: measured (p_i) or calculated (p_{it}).

Break Mean Effective Pressure (BMEP) is the mean effective pressure calculated from the dynamometer power (torque). This is the actual output of the internal combustion engine, at the crankshaft (p_e).

$$p_e = \eta_m p_i$$

Unit: MPa

BMEP takes into account the engine mechanical efficiency (η_m).

The higher the p_e, the greater the power obtained from an engine of comparable displacement and rotational speed.

Power

Computational quantity, taking into account the torque and rotational speed of the engine. Engine power is characterized by the ability of the engine to perform a certain amount of work in a certain amount of time.

Effective power (N_e) is the difference between the indicated power and the power lost to overcome the frictional resistance of the engine mechanisms and the power consumed by the accessories. It can be calculated on the basis of the average value of the torque measured at the crankshaft.

$$N_e = 2\pi \cdot n_s \cdot M_o, kW$$

n_s – engine rotational speed,
M_o – torque

4 stroke engine (multiple cylinders)

$$N_e = \frac{1}{2} \cdot V_{ss} \cdot n_s \cdot p_e$$

n_s – engine rotational speer,
V_{ss} – engine displacement
p_e – BMEP

Fuel consumption

Unit fuel consumption (G_e) – mass fuel consumption per unit of time
Unit: kg/h

$$G_e = \frac{m_{fuel}}{t}, \frac{kg}{h}$$

Specific fuel consumption (g_e) – the amount of fuel consumed by engine for each unit of effective power
Unit: kg/kWh

$$g_e = \frac{G_e}{N_e}, \frac{kg}{kW \cdot h}$$

Efficiency

Theoretical efficiency – ratio of the theoretical work and the amount of heat supplied to the system during one cycle

$$\eta_t = \frac{W_t}{Q}$$

Indicated efficiency – ratio of the indicated work and theoretical work

$$\eta_i = \frac{W_i}{W_t} = \frac{W_i}{\eta_t Q}$$

Heat efficency–ratio of the indicated work and the amount of heat supplied to the system during one cycle

$$\eta_c = \frac{W_i}{Q} = \frac{W_t}{Q}\frac{W_i}{W_t}$$

Efficiency

Mechanical efficency – measure of mechanical losses in engine mechanisms and losses incurred on the drive of engine accessories (ratio of effective and indicated power)

$$\eta_m = \frac{N_e}{N_i}$$

Total efficency – total measure of energy delivered to the engine in fuel. It is expressed as the ratio of useful work to the total amount of heat generated by engine during one work cycle

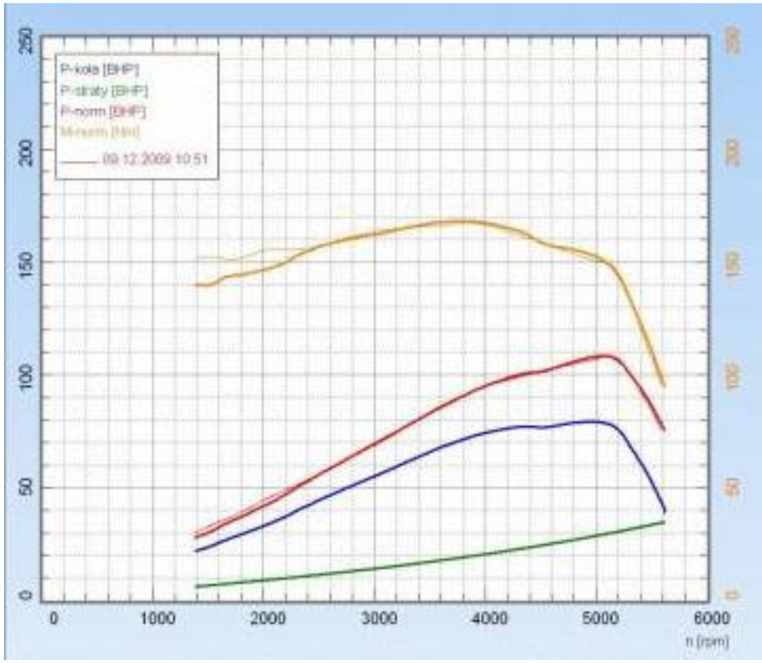
$$\eta_o = \frac{W_u}{Q} = \frac{N_e}{G Q_V}$$

Engine type	Total efficiency η_o	Theoretical efficiency η_t	Heat efficiency η_c	Indicated efficiency η_i	Mechanical efficiency η_m
SI	$0,22 \div 0,38$	$0,35 \div 0,45$	$0,30 \div 0,38$	$0,65 \div 0,80$	$0,75 \div 0,90$
CI	$0,30 \div 0,52$	$0,50 \div 0,65$	$0,40 \div 0,58$	$0,75 \div 0,85$	$0,75 \div 0,90$

Engine characteristics

Values of the engine operational parameters change depending on the rotational speed and engine load, the regulated amount of air-fuel mixture supplied per cycle (SI engines) or the amount of the injected fuel dose (CI engines), on the charge composition, ignition or injection advance and from the parameters of the environment

Engine characteristics are the interdependences between the mentioned parameters presented graphically



Engine characteristic types

- **Speed characteristics** – created in function of engine rotational speed

  ex. external, universal

- **Load characteristics** – created in function of engine power or torque

  ex. load, control (injection timing angle, ignition timing angle, composition of the fuel mixture, etc.)

- **Other characteristics** – ex. propeller power curve (for marine application, altitude (for aviation engines)

Maximum power curve (external characteristic)

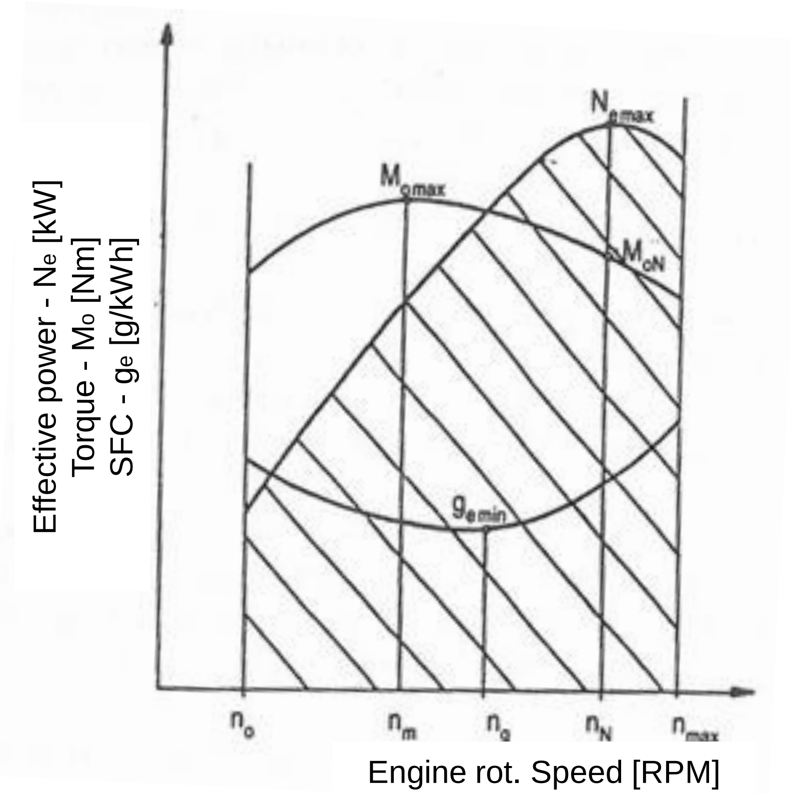
- represents power as a function of engine speed

$$N_e = f(n)$$

- The power is measured at the engine dynamometer while supplying the engine with a full dose of fuel: full setting of the injection pump – CI engine or the full throttle opening – SI engine

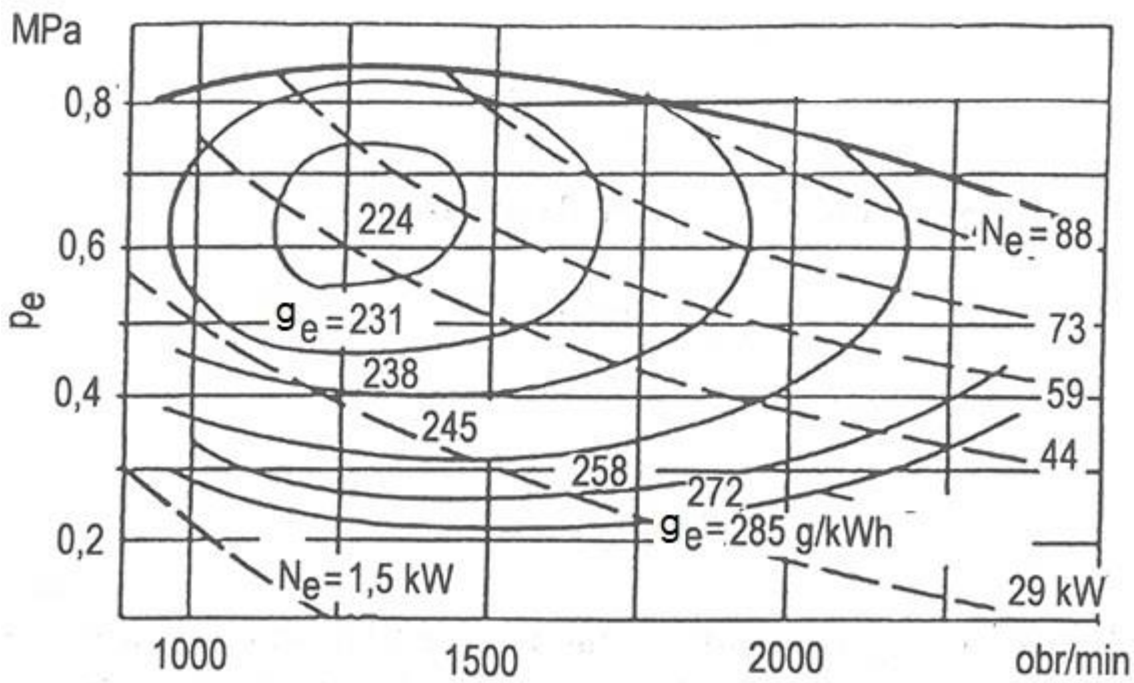
- It starts from the lowest rotational speeds at which the engine is still capable of normal operation (idle) to engine rated speed (or slightly more)

- The external characteristics of CI engines do not show a maximum on the power curve in the range of useful rotational speed and are slightly less convex comparing to SI



Universal characteristics

- Represents the regions of constant specific fuel consumption (g_e) and constant power curves (N_e) in the p_e- n or M_o- n coordinate system
- It is based on multiple load characteristics or partial speed characteristics

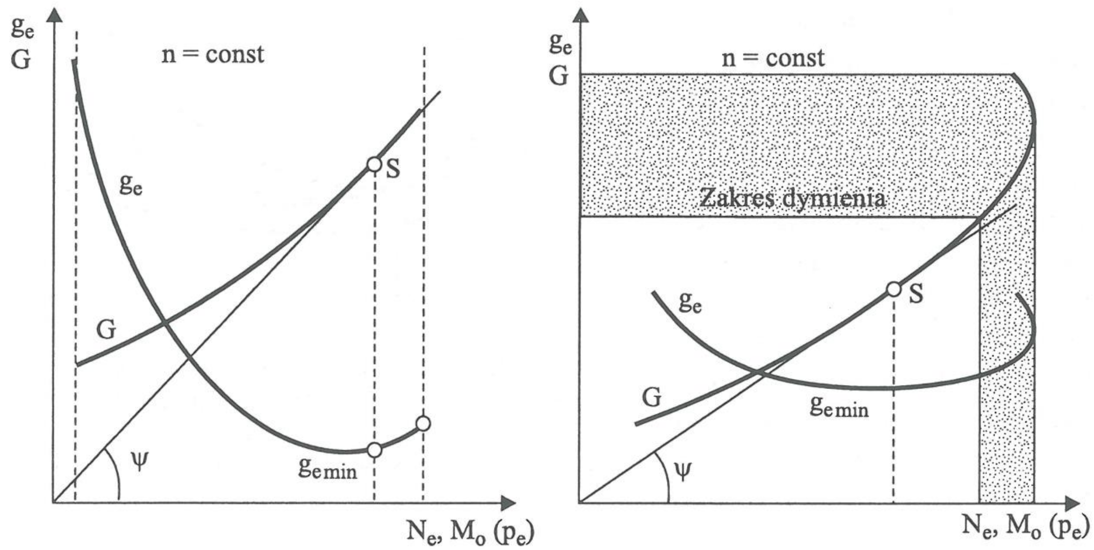


Load characteristics

- Shows the dependence of unit (G_e) and specific fuel consumption (g_e) on engine torque (M_o), BMEP (p_e) or effective power (N_e)

- **Performed at constant rotational speed n = const.**

- The characteristics of SI and CI engines, as in the case of external characteristics, differ in shape



Basic formulas

Engine power:

$$N_e = \frac{M_o n}{9554}, kW$$

M_o – torque, N·m
n – engine rotational speed, RPM

BMEP:

$$p_e = \frac{120 N_e}{V_{ss} n}, MPa$$

V_{ss} – engine total displacement, dm^3

Specific fuel consumption:

$$g_e = \frac{G_e}{N_e} \cdot 1000, g/kWh$$

G_e – unit fuel consumption, kg/h