Internal Combustion Engines

ENGINE CHARACTERISTICS

Engine performance parameters are power, torque and specific fuel consumption.

Brake torque is normally measured with a dynamometer – engine is mounted on a test bed and the shaft is connected to the dynamometer rotor. The rotor is coupled electromagnetically, hydraulically or by mechanical friction to a stator, which is supported in low friction bearings. Torque exerted on the stator with the rotor turning is measured by balancing the stator with weights, springs or pneumatic means. The torque exerted by the engine is,

\[ T = Fb \]

The power delivered by engine is, product of torque and angular speed,

\[ P = 2\pi NT \]

Brake power is \( P_b \)
Engine Performance Parameters
Engine Performance Parameters

**Torque (effective)**

\[ T_e = F \cdot b \quad \text{(Nm)} \]

**Power (effective)**

\[ N_e = T_e \cdot \omega \quad \text{(W)} \]

\[ N_e = \text{Work} \cdot \text{Angular Speed} \]

\[ N_e = W_e \cdot \omega = P_{me} \cdot V_h \cdot \omega \]

- \( P_{me} \): MPa
- \( V_h \): liter
- \( n \): r.p.m (rev per minute)
- \( z = 1 \) for 2-stroke engine
- \( z = 2 \) for 4-stroke engine

\[ N_e = \left( \frac{P_{me} \cdot V_h \cdot n}{z \cdot 60} \right) \quad \text{(kW)} \]
Engine Performance Parameters

\[ V_{\text{fuel}} : \text{measured volume (cm}^3\text{)} \]
\[ \rho_{\text{fuel}} : \text{fuel density (g/cm}^3\text{)} \]
\[ \Delta t : \text{time for consumption (s)} \]
\[ m_{\text{fuel}} = \frac{V_{\text{fuel}} \rho_{\text{fuel}}}{\Delta t} \text{ (g/s)} \]
\[ b_e = m_{\text{fuel}} \times 3600 / N_e \text{ (g/kWh)} \]

Specific fuel consumption

Engine Performance Parameters

Specific fuel consumption, \( b_e \) [g/kW- h]

\[ \text{Hu} : \text{Lower heating value [kJ / kg-fuel]} \]
\[ 1 \text{ kWh} = 860 \text{ kcal} \]
\[ 1 \text{ kWh} = 3600 \text{ kJ} \]
\[ \eta_e = \frac{(3600) / ((b_e / 1000) \text{ Hu})}{\times 100 \%} \]

Efficiency (effective)
Engine Performance Parameters

Indicated work per cycle

Cylinder pressure data is used to calculate the work transfer from the gas to the piston – cylinder pressure vs cylinder volume throughout the cycle gives p-V diagram.

Indicated work per cycle $W_{ci}$ is obtained by integrating around the curve to obtain the area enclosed on the diagram

$$W_{ci} = \int p \, dV$$

Pumping work during gas exchange is subtracted to obtain net indicated work per cycle.

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Engine Performance Parameters

Mechanical efficiency

Part of the gross indicated work per cycle or power is used to expel exhaust gases and to induct fresh charge. An additional portion is used to overcome the friction of bearings, pistons, and other mechanical components of the engine and to drive engine accessories. All these power req are called friction power, $P_f$

$$P_g = P_b + P_f$$

Mechanical efficiency,

$$\eta_m = \frac{P_b}{P_g} = 1 - \frac{P_f}{P_g}$$
Engine Performance Parameters

Road load power

\[
P_r = C_R M_v g + \frac{1}{2} \rho_d C_D A_v S_v^2 S_v
\]

- \( C_R \): Coefficient of rolling resistance, \((0.012 – 0.015)^3\)
- \( M_v \): Mass of vehicle
- \( C_D \): Drag coefficient \((0.3 – 0.5)^3\)
- \( g \): Accn due to gravity of vehicle
- \( S_v \): Vehicle speed

\[ \ell = \frac{P n}{N} \]

Mean effective pressure

Where \( n_R \) is the number of crank rev for each power stroke per cylinder
\((n_R =1 \text{ for 2-stroke engines, } n_R =2 \text{ for 4-stroke engines})\)

Mean eff pressure is,

\[
P_{me} = \frac{P n_R}{V_d N}
\]

For naturally aspirated SI-engines, \(850 – 1050 \text{ kPa at engine speed for max torque (around 3000 rpm)}, \)
\text{ turbocharged SI engines, } \(1250 – 1700 \text{ kPa.} \)

For CI-engines, \(700 – 900 \text{ kPa} \)
### Engine Performance Parameters

#### Indicated power

Forces acting on the piston,

\[ P = p_{mi} \pi \frac{D^2}{4} \]

Work done is

\[ W = p_{mi} \pi \frac{D^2}{4} S \]

Indicated power, for n [rpm] and 4-stroke engine

\[ \text{Power}_i = \pi \sqrt[3]{\frac{D^2}{4}} n \frac{p_{mi}}{2 \times 60} \]

\[ \text{Power}_i = \pi V_h p_{mi} \frac{n}{2 \times 60} \]

#### Operating cycle

<table>
<thead>
<tr>
<th>Engine type</th>
<th>Operating cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spark-ignition engines:</td>
<td></td>
</tr>
<tr>
<td>Small (e.g., motorcycles)</td>
<td>25-45</td>
</tr>
<tr>
<td>Power cars</td>
<td>45</td>
</tr>
<tr>
<td>Trucks</td>
<td>45</td>
</tr>
<tr>
<td>Large gas engines</td>
<td>25-45</td>
</tr>
<tr>
<td>Water cooled engines</td>
<td>45</td>
</tr>
</tbody>
</table>

#### Compression ratio

<table>
<thead>
<tr>
<th>Engine type</th>
<th>Compression ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spark-ignition engines:</td>
<td></td>
</tr>
<tr>
<td>Small (e.g., motorcycles)</td>
<td>6-11</td>
</tr>
<tr>
<td>Power cars</td>
<td>8-10</td>
</tr>
<tr>
<td>Trucks</td>
<td>7-9</td>
</tr>
<tr>
<td>Large gas engines</td>
<td>8-12</td>
</tr>
<tr>
<td>Water cooled engines</td>
<td>8-9</td>
</tr>
</tbody>
</table>

#### Bore, Stroke

<table>
<thead>
<tr>
<th>Engine type</th>
<th>Bore, Stroke</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spark-ignition engines:</td>
<td></td>
</tr>
<tr>
<td>Small (e.g., motorcycles)</td>
<td>0.65-0.85 m</td>
</tr>
<tr>
<td>Power cars</td>
<td>1.2-0.9</td>
</tr>
<tr>
<td>Trucks</td>
<td>0.89-0.83</td>
</tr>
<tr>
<td>Large gas engines</td>
<td>0.22-0.45</td>
</tr>
<tr>
<td>Water cooled engines</td>
<td>0.57 dm³ per chamber</td>
</tr>
</tbody>
</table>

#### Speed, rev/min

<table>
<thead>
<tr>
<th>Engine type</th>
<th>Speed, rev/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spark-ignition engines:</td>
<td></td>
</tr>
<tr>
<td>Small (e.g., motorcycles)</td>
<td>4500-7500</td>
</tr>
<tr>
<td>Power cars</td>
<td>3000-5000</td>
</tr>
<tr>
<td>Trucks</td>
<td>3600-5000</td>
</tr>
<tr>
<td>Large gas engines</td>
<td>6000-8000</td>
</tr>
<tr>
<td>Water cooled engines</td>
<td>10000-12000</td>
</tr>
</tbody>
</table>

#### Weight, kg

<table>
<thead>
<tr>
<th>Engine type</th>
<th>Weight, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spark-ignition engines:</td>
<td></td>
</tr>
<tr>
<td>Small (e.g., motorcycles)</td>
<td>5.5-6.5</td>
</tr>
<tr>
<td>Power cars</td>
<td>6.5-7.5</td>
</tr>
<tr>
<td>Trucks</td>
<td>4.3-5.2</td>
</tr>
<tr>
<td>Large gas engines</td>
<td>3.7</td>
</tr>
<tr>
<td>Water cooled engines</td>
<td>2.3-3.5</td>
</tr>
</tbody>
</table>

#### Approx. Price, g/kW·h

<table>
<thead>
<tr>
<th>Engine type</th>
<th>Approx. Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spark-ignition engines:</td>
<td></td>
</tr>
<tr>
<td>Small (e.g., motorcycles)</td>
<td>250</td>
</tr>
<tr>
<td>Power cars</td>
<td>270</td>
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<tr>
<td>Trucks</td>
<td>300</td>
</tr>
<tr>
<td>Large gas engines</td>
<td>200</td>
</tr>
<tr>
<td>Water cooled engines</td>
<td>300</td>
</tr>
</tbody>
</table>

#### Engine Performance Parameters

**Indicated power**

\[ P = p_{mi} \pi \frac{D^2}{4} \]

**Forces acting on the piston,**

\[ W = p_{mi} \pi \frac{D^2}{4} S \]

**Work done is**

\[ \text{Power}_i = \pi \sqrt[3]{\frac{D^2}{4}} n \frac{p_{mi}}{2 \times 60} \]

\[ \text{Power}_i = \pi V_h p_{mi} \frac{n}{2 \times 60} \]
Engine Performance Parameters

Effective power

\[ P = p_{me} V_n \frac{n}{2 \times 60} \]

Power can be increased by increasing stroke volume (increasing cylinder diameter or stroke, number of cylinders), engine speed or mean effective pressure.

Stroke volume
- increasing the stroke, inc mean piston speed, inc wear and reduces volumetric efficiency
- inc bore, inc cylinder temperatures
- inc number of cylinders, easy start up, better balancing, inc weight, inc engine length and vibrations

Engine speed

reduces volumetric efficiency, inc inertia forces – valves, inc cylinder temperatures, reduces time available for combustion (Diesel engines)

Mean effective pressure

advance technology required, inc of compression ratio
- requires wider wall thickness
turbocharging
Engine Performance Parameters

Specific fuel consumption

\[ sfc = \frac{m_f}{P} \]

Low values of sfc are desirable, for SI-engines 250 – 270 g/kW.h and for CI-engines, 200 g/kW.h
Engine Performance Parameters

Diesel engine

Emission measurement according to ECE R-49
Engine Performance Parameters

![Diagram 1: Engine Performance Parameters](image1)

- Effective Torque [Nm]
- Specific Consumption [g/kWh]
- Rpm [1/min]

Engine Performance Parameters

![Diagram 2: Engine Performance Parameters](image2)

- Mean Piston Speed [m/s]
- Horsepower [kW]
- Engine Speed [rev/min]