Ideal Standard Cycles

Introduction
Comparison between thermodynamic and mechanical cycles
Performance parameters
imep, bmeq, mechanical efficiency, indicated eff., volumetric eff.
Ideal cycles and thermal efficiencies
Otto cycle, Diesel cycle, Dual cycle
Comparison of cycles
Deviations from actual engine cycles
Ideal Air Standard Cycles

References:


Assumptions

Air standard cycles, serve as introduction to the more detailed and accurate models of IC engines provide insight into some of the important parameters that effect engine performance

Assumptions;

• Neglect heat transfer to and from cylinder walls,
• Replace combustion process by a heat addition process that occurs at constant volume (in Otto cycle) or at constant pressure (in Diesel cycle),
• Do not consider gas exchange process,
• Assume cylinder charge as a perfect gas (cp and cv are assumed constant) which is pure air.
The Otto cycle is used as a basis of comparison for SI engines. The cycle consists of four processes:

1 – 2 isentropic compression from $V_1$ to $V_2$
2 – 3 addition of heat $Q_{23}$ at constant volume
3 – 4 isentropic expansion to the original volume
4 – 1 rejection of heat $Q_{41}$ at constant volume
Otto Cycle

Work done during the cycle, 1-2-3-4 is,

\[ W_{cycle} = \int p \, dV = \int T \, ds \]

Constant volume heat input to the cycle per unit mass of working fluid

\[ Q_{23} = \int_{T_2}^{T_3} c_v \, dT = c_v (T_3 - T_2) \]

Constant volume heat extraction from the cycle per unit mass

\[ Q_{41} = -\int_{T_4}^{T_1} c_v \, dT = -c_v (T_1 - T_4) = c_v (T_4 - T_1) \]

Otto Cycle

1st law of thermodynamics \[ dE = dQ - dW \]

\[ dE = 0 \]

Thermal efficiency

\[ \eta_{t-otto} = \frac{W}{Q_{23}} = \frac{\text{work done}}{\text{heat input}} \]

\[ \eta_{t-otto} = \frac{Q_{23} - Q_{41}}{Q_{23}} = 1 - \frac{Q_{41}}{Q_{23}} \]

\[ \eta_{t-otto} = 1 - \frac{T_4 - T_1}{T_3 - T_2} \]
Otto Cycle

Initial pressure $p_1$ and temperature $T_1$

using $p_1 V_1^k = p_2 V_2^k$ for an adiabatic compression

and $pV = mRT$ from ideal gas law

$$p_2 = p_1 \left(\frac{V_1}{V_2}\right)^k \quad T_2 = T_1 \left(\frac{V_1}{V_2}\right)^{k-1} \quad k = \frac{c_p}{c_v}$$

compression ratio $\varepsilon = \frac{V_1}{V_2}$ ( sıkıştırma oranı)

$$T_2 = T_1 \varepsilon^{k-1}$$

from $2 \rightarrow 3$, constant volume heat addition

$$p_2 V_2 = mRT_2 \quad p_1 V_3 = mRT_3 \quad V_2 = V_3$$

$$T_3 = T_2 \frac{p_3}{p_2}$$

defining $\beta = \frac{p_3}{p_2}$ "pressure ratio" ( basınç artış oranı)

$$T_3 = T_1 \beta \varepsilon^{k-1}$$
Otto Cycle

from 3 → 4, adiabatic expansion,

\[ p_4V_4^k = p_3V_3^k \]
\[ p_4V_4V_4^{k-1} = p_3V_3V_3^{k-1} \]

From ideal gas law

\[ p_4V_4 = mRT_4 \quad p_3V_3 = mRT_3 \]

\[ \frac{V_4}{V_3} = \frac{V_4}{V_2} = \varepsilon \]
\[ T_4V_4^{k-1} = T_3V_3^{k-1} \quad T_4 = \frac{T_3}{\varepsilon^{k-1}} \quad T_4 = T_1 \beta \]

Thermal Efficiency

Thermal efficiency of Otto cycle is given by,

\[ \eta_{\text{otto}} = 1 - \frac{T_4 - T_1}{T_3 - T_2} \]

placing the temperatures \( T_\beta, T_3 \) and \( T_4 \) in terms of \( T_1 \)

\[ \eta_{\text{otto}} = 1 - \frac{1}{\varepsilon^{k-1}} \]
Thermal Efficiency

![Graph showing thermal efficiency vs. compression ratio.]

Diesel Cycle

![Diagram of the diesel cycle showing pressure-volume and entropy diagrams.]
Diesel Cycle

Work done during the cycle, 1-2-3-4 is,

\[ W_{\text{cycle}} = \oint p \, dV = \oint T \, ds \]

Constant pressure heat input to the cycle per unit mass of working fluid

\[ Q_{23} = \int_{T_2}^{T_3} c_p \, dT = c_p \, (T_3 - T_2) \]

Constant volume heat extraction from the cycle per unit mass

\[ Q_{41} = -\int_{T_4}^{T_1} c_v \, dT = -c_v \, (T_1 - T_4) = c_v \, (T_4 - T_1) \]

Diesel Cycle

1st law of thermodynamics

\[ dE = dQ - dW \]

\[ dE = 0 \]

Thermal efficiency

\[ \eta_{\text{diesel}} = \frac{W}{Q_{23}} = \frac{\text{work done}}{\text{heat input}} \]

\[ \eta_{\text{diesel}} = \frac{Q_{23} - Q_{41}}{Q_{23}} = 1 - \frac{Q_{41}}{Q_{23}} \]

\[ \eta_{\text{diesel}} = 1 - \frac{T_4 - T_1}{k(T_3 - T_2)} \]
Diesel Cycle

\[ T_2 = T_1 \epsilon^{k-1} \]

\[ T_3 = T_2 \frac{V_3}{V_2} = T_1 \alpha \epsilon^{k-1} \]

\[ T_4 = \frac{T_3 \alpha^{k-1}}{\epsilon^{k-1}} = T_1 \alpha^k \]

Diesel Cycle

Defining “cut-off ratio” or “load ratio” (hacim artış oranı)

\[ \alpha = \frac{V_3}{V_2} \]
Thermal Efficiency

Thermal efficiency of Diesel cycle is given by,

\[ \eta_{\text{diesel}} = 1 - \frac{T_4 - T_1}{T_3 - T_2} \]

placing the temperatures \( T_2, T_3 \) and \( T_4 \) in terms of \( T_1 \)

\[ \eta_{\text{diesel}} = 1 - \frac{1}{\varepsilon^{k-1} k (\alpha - 1)} \]

As the value of \( \alpha \) increases (heat addition is extended towards expansion) the efficiency is reduced due to additional heat required to compensate the expansion.
Work done during the cycle, 1-2-3'-3-4 is,

\[ W_{\text{cycle}} = \oint p \, dV = \oint T \, ds \]

Constant volume heat input followed by constant pressure heat input to the cycle per unit mass of working fluid

\[ Q_{23} = c_v (T_3 - T_2) + c_p (T_3 - T_y) \]

Constant volume heat extraction from the cycle per unit mass

\[ Q_{41} = \int_{T_1}^{T_4} c_v \, dT = -c_v (T_4 - T_1) = c_v (T_4 - T_1) \]
Dual Cycle

Thermal efficiency

\[ \eta_{\text{t, duan}} = 1 - \frac{c_v(T_4 - T_1)}{c_v(T_3 - T_2) + c_p(T_3 - T_2)} \]

\[ T_2 = T_1 \varepsilon^{k-1} \]

\[ T_3' = T_1 \beta \varepsilon^{k-1} \]

\[ T_3 = T_1 \beta \alpha \varepsilon^{k-1} \]

\[ T_4 = T_1 \alpha^k \beta \]
Thermal Efficiency

Thermal efficiency of Dual cycle is given by,

\[ \eta_{\text{dual}} = 1 - \frac{1}{e^{k-1}} \frac{\beta \alpha^k - 1}{\beta - 1 + k\beta (\alpha - 1)} \]

Putting \( \alpha = 1 \) Otto cycle thermal efficiency
\( \beta = 1 \) Diesel cycle thermal efficiency

is obtained

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Thermal Efficiency

Otto cycle

\[ \eta_{\text{th-Otto}} = 1 - \frac{1}{e^{k-1}} \]

Diesel cycle

\[ \eta_{\text{th-Diesel}} = 1 - \frac{1}{e^{k-1}} \frac{\alpha^k - 1}{k(\alpha - 1)} \]

Dual cycle

\[ \eta_{\text{th-Dual}} = 1 - \frac{1}{e^{k-1}} \frac{\beta \alpha^k - 1}{\beta - 1 + k\beta (\alpha - 1)} \]
Comparison of Ideal Cycles

For $\alpha > 1$ and $k > 1$

$$\frac{\alpha^k - 1}{k(\alpha - 1)}$$

term is greater than 1

therefore $\eta_{t-otto} > \eta_{t-diesel}$ for a constant value of compression ratio

Also $\eta_{t-otto} > \eta_{t-dual} > \eta_{t-diesel}$

efficiency of Dual cycle lies between Otto and Diesel cycles according to the value of $\beta$

Comparison of Ideal Cycles

In real engines,

SI engines have a compression ratio between 10:1 to 12:1

this value is limited due to engine knock

CI engines have compression ratio higher than 14:1 to provide temperature and pressure required for self ignition of the fuel

compression ratio of 16:1 to 18:1 is sufficient for efficiency, but used for improving ignition quality

high compression ratio increases thermal and mechanical stresses