Gas Turbines

Monday, March 24, 2025 12:08 PM

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Basic Principle

- It is rotg mc that use gas as working fluid.
- It consists of compressor, combustor, heater, turbine.
- Compressor is supplied with air at ambt conds & raise its pr & temp to reqd limit for combustion.
- Compressed air enters combustion chamber/ combustor where it heats fuel burning in chamber.
- Combustion prodts (gas, air) are expanded in turbine by mech work.
- Gases are then exhausted out to atm as in open-cycle GT.

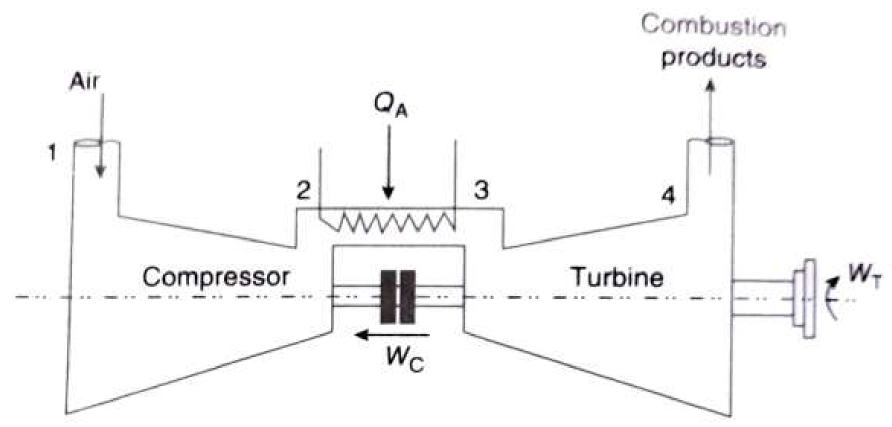

Fig. 12.1 *Gas Turbine: Working Principle*

Joule/ Brayton Cycle

This cycle is used to analyse simple gas turbines.

Assumptions for analysis of ideal cycle:

1. Effect of frxn on mc & fluid is neglected.
2. Change in PE & KE of medium due to overall process is neglected. So pr losses in heat xchger and passages in absent.
3. No inc in mass flow rate due to addn of fuel.
4. Working fluid is perfect gas. Sp heat remain constant at all temp for turbine & compressor.
5. Radn loss are neglected.

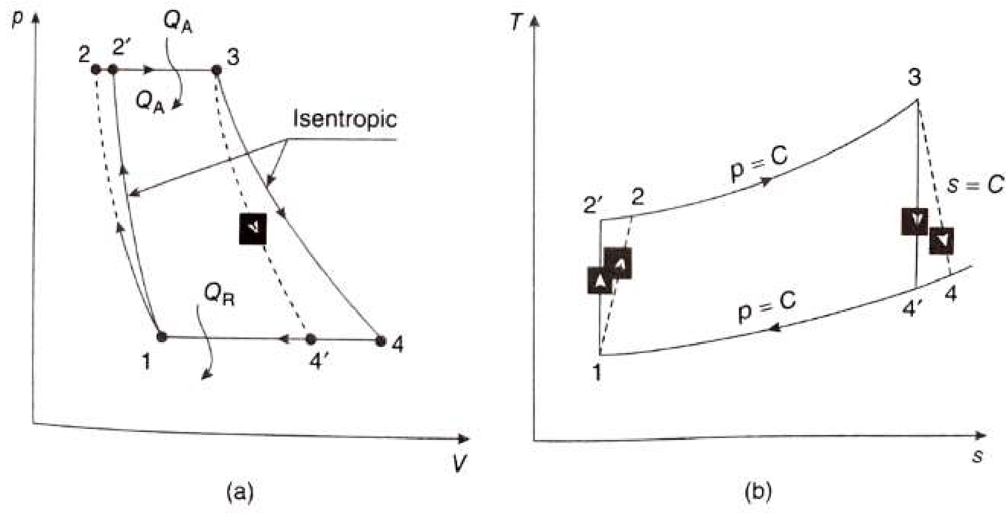

Fig. 12.2 *Joule Cycle: Ideal and Actual Processes*

[Simple Cycle with actual & ideal process is shown in P-V, T-S diagram]

Ideal Cycle Analysis

1. **1-2**
   - Isentropic Compression
   - Temp inc from T1→T2
   - Pr inc from P1→P2
   - Volm dec from V1→V2
   - $WD = W_c = C_p(T_2 - T_1) = h_2 - h_1$
   - heat transfer is 0
2. **2-3**
   - Constant Pressure Heat Addition
   - Entropy inc, Temp inc from T2→T3
   - Volm inc from V2→V3
   - $WD = P(V_3 - V_2)$
   - Heat transfer in process $= Q_A = C_p(T_3 - T_2) = h_3 - h_2$
3. **3-4**
   - Isentropic Expansion
   - Temp dec from T3→T4
   - Pr dec from P3→P4
   - Volm inc from V3 to V4
   - $WD = C_P(T_3 - T_4) = h_3 - h_4$
   - Heat transfer is 0
4. **4-1**
   - Constant Pressure Heat Rejection
   - Temp dec from T4→T1
   - Volm dec from V4→V1
   - $WD = P(V_4 - V_1)$
   - Heat transfer in process $= Q_R = C_p(T_4 - T_1) = h_4 - h_1$

- Net WD/Cycle = heat added − heat rejected $= Q_A - Q_R = (h_3 - h_4) - (h_2 - h_1)$
  h → enthalpy of working fluid in $\frac{kJ}{kg}$
  It is diff of turbine work & compressor work.
- Work Ratio is dfd as ratio of net WD to turbine work (+ve work)
  Let $\frac{T_2}{T_1} = \frac{T_3}{T_4} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = R$; [γ → Ratio of Sp Heat]

$$W_R = \frac{(h_3 - h_4) - (h_2 - h_1)}{h_3 - h_4} = \frac{C_P}{C_P} \cdot \frac{(T_3 - T_4) - (T_2 - T_1)}{T_3 - T_4} = 1 - \frac{T_2 - T_1}{T_3 - T_4}$$

$$= 1 - \frac{T_1}{T_3}\left(\frac{\frac{T_2}{T_1} - 1}{1 - \frac{T_4}{T_3}}\right) = 1 - \frac{T_1}{T_3}\left(\frac{R - 1}{1 - \frac{1}{R}}\right) = 1 - R\frac{T_1}{T_3}$$

- Thermal Eff of cycle is ratio of net WD to heat supplied.

$$\eta = \frac{\text{Net WD}}{\text{Heat Added}} = \frac{W_T - W_C}{Q_A} = 1 - \frac{T_4 - T_1}{T_3 - T_2} = 1 - \frac{T_1}{T_2} = 1 - \frac{1}{R}$$

<u>Actual Cycle Analysis</u>

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<u>Clsf of GT:</u>

1. **Constant Pr Combustion**
   - **Direct Open Cycle**
   - **Indirect Open Cycle**
   - **Direct Close Cycle**
   - **Indirect Close Cycle**
2. **Constant Volm Combustion GT**

In the case of constant volume combustion, gas turbine heat addition takes place at constant volume in the combustion chamber. As it entails valves and consequent intermittent operation, it become obsolete and is replaced by constant pressure gas turbine.

<u>Working Principle of Constant Pr Gas Turbines</u>

1. **<u>Direct Open Cycle</u>**

The direct open-cycle gas turbine is shown in Figure 12.6. In the direct open-cycle gas turbine, air enters the compressor at point 1, where it is compressed to point 2. The air then enters the combustion chamber or the reactor where it receives heat at constant pressure (ideal cycle) and emerges hot at point 3. The gas that comes out of the combustion chamber expands in the turbine to point 4. The hot exhaust mixes with the atmosphere outside the cycle and a fresh cool supply is taken in at point 1. Part of the turbine power is used to run the compressor and auxiliaries.

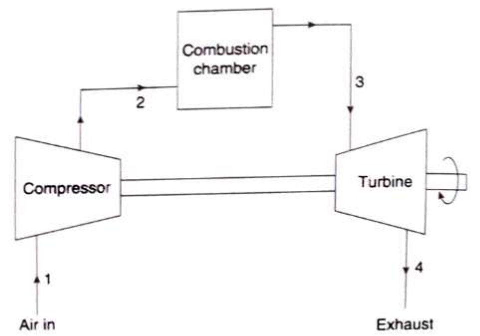

Fig. 12.6 *Direct Open Cycle Gas Turbine*

2. **<u>Indirect Open Cycle</u>**
   - Elements are similar to direct open cycle but air is secondary fluid that receive heat from primary coolant in heat xchger.
   - Suitable when env concerns restrict direct air heating.
     Ex: Nuclear reactors, where ra release may spread to atm.

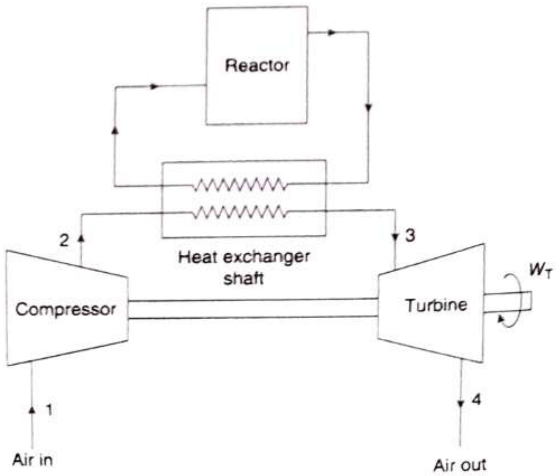

Fig. 12.7 *Indirect Open Cycle Gas Turbine*

3. **Direct Close Cycle**
   - Gas coolant is heated in reactor, expanded by turbine, cooled in heat xchger, compressed back to reactor.
   - Working fluid can be air or other gas. He is most suitable.
   - No effluent of ra gas pass into atm under normal working conds.
   - This cycle permits pressurization of working fluid with consequent redn in plant size.

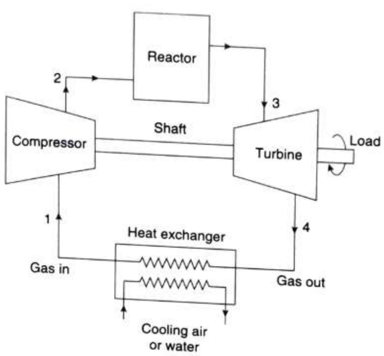

Fig. 12.8 *A Direct Closed-Cycle Turbine*

4. **Indirect Close Cycle**
   - It combines indirect open cycle & direct close cycle, reactor is separated from working fluid by heat xchger.
   - Working gas rejects heat to atm via heat xchger.
   - Primary coolant can be water, liquid metal, gas like Helium.

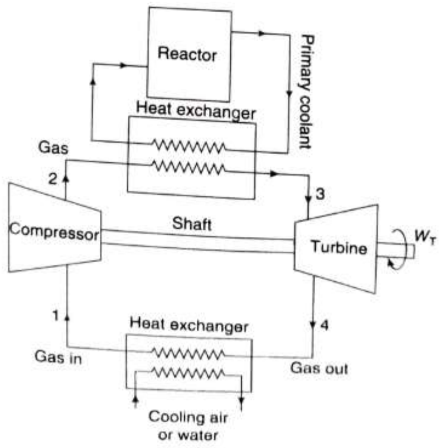

Fig. 12.9 *Indirect Closed-Gas Turbine Cycle*

Open vs Closed Cycle GT

	Open	**Close**
Working Fluid	Air	Any
Heating Method	Direct heating of air in combustor cause erosion & corrosion of turbine blades due to contaminated gases.	Indirect heating eliminate this. So more eff & life of blades.
Working Pr	Atm, so larger plant size	> atm, so smaller plant size.
Heat Transfer Coff	Small due to low working pr	Larger due to high working pr.
Part Load Eff	Poor as load regulation is done by varn of turbine inlet temp.	Better as load is regulated by changing fluid pr by varying qty of working fluid at constant temp.
Cost of Power	Use of good quality fuel inc cost.	Inferior quality fuel can be used bc of indirect heating.
Air Filter	Reqd	Not reqd bc of indirect heating
Plant Eff, Power Op	Low bc of low working pr.	Higher bc of high working pr.
	Simple	Complex, need bulky air heaters
Coolant	Atm act as coolant.	Needed to pre-cool turbine exhaust bf it enters compressor.
Rigidity	Not reqd (low working pr)	Must be rigid and strong to handle high working pr.
Cost	Cheap System	System should be air-tight, so costly