Gas Turbine-COMPRESSOR

Dr. Walid Abdelghaffar
Gas turbine categories

Single shaft

Figure 8 - Single shaft turbine.
Gas turbine categories

Single shaft Hot Driven
Gas turbine categories

Single shaft Cold Driven
Gas turbine categories

Dual shaft (Split Shaft)

Diagram showing a dual shaft gas turbine with components labeled as follows:
- Air
- Fuel
- Starting Motor
- Compressor
- H-p Turbine
- L-p Turbine
- Combustion Chamber
- Exhaust
- Generator
The advantage of this arrangement is greater flexibility.

- The load may be operated at varying speeds while the compressor speed remains constant.
- Conversely, the load speed may be constant as in the case of a generator while the compressor speed may be varied.
- Another advantage of the dual shaft machine is that a smaller starting motor may be used, as during start-up it is only necessary to turn the compressor and the high-pressure turbine.
The gas generation section of the gas turbine brings air in from the compressor to mix with fuel in the combustion chamber to create hot expanding gases that can be harnessed.
Twin spool shafts have one shaft running inside another. There are two separate compressors and two separate turbines. The gas turbine engine shown in has a twin spool gas generation section and split shaft type power section.

Figure 10 - Twin spool turbine with a power turbine.
A highly efficient and capable compressor is critical for the efficient operation of a gas turbine. Two types of compressors are used in gas turbines:

- **Centrifugal or radial**
- In small gas turbines, centrifugal compressors are often used, in combination with several axial stages. The majority of large gas turbines use a **Multi-Stage Axial Compressor**.
- Since the compressor absorbs up to $\frac{2}{3}$ of the energy provided by the fuel, it must be structurally sound, as well as efficient.
**Purpose**

The purpose of the compressor section is to compress air for cooling and combustion.

The compressor draws in atmospheric air through the air inlet and increases its pressure while reducing its volume.

In an axial flow compressor the air flows axially. This means that the air flows in a relatively straight path in line with the axis of the gas turbine.
Axial Flow Compressor

Gas Turbine-COMPRESSOR

Dr. Walid Abdelghaffar
Axial Flow Compressor

A typical Industrial Axial Flow Compressor
Axial Flow Compressor

**HITACHI GAS TURBINE**

*The Compressor*

- 17 stage Axial Compressor
- High Efficiency Transonic Aerofoil
- High Pressure Ratio of 14.7
- Corrosion Resistant 15 Cr-Steel Blade

High Efficient and Reliable Compressor
This type of compressor operates on a principle similar to a turbine, but acting in reverse.

The moving blades act upon the air so as to increase its velocity and discharge it axially into the next row of fixed blades, rather as though each moving blade was a small section of a propeller.

The fixed blades tend to slow the air down in its passage through them and so raise its pressure.

If the moving blades are properly shaped, they will cause the air to be compressed in its passage through them so that compression takes place in both fixed and moving blading.

If the pressure rise in each is equal, the compressor is symmetrically staged and is similar to a reaction turbine (in reverse).
The main components of an axial flow compressor are the:

- case
- rotor
- stator
The compressor case contains the rotor and the stator.

The case is divided into halves. The upper half may be removed for inspection or maintenance of the rotor and stator blades while the bottom half remains in place.
Axial Flow Compressor components: Case

• The case of an axial flow compressor has the following functions:

  • support the stator vanes

  • provide the outside wall for the axial path of airflow

  • provide a means for extracting compressed air
Compressor Components: Rotor

The rotor is the rotating element of the compressor. The rotor contains blades fixed on a spindle, drum, or wheel.

These blades push air to the rear in the same way a propeller does. The movement of air is caused by the angle and the shape of the blades.

When turning at high speed, the rotor takes in air at the compressor inlet, increases the air pressure, and accelerates the air toward the rear of the engine through a series of stages.

Energy is transferred from the compressor to the air as velocity energy.
Compressor Components: Rotor Blades

Rotor blades are usually made of stainless steel. They are usually fitted into the rotor disks by either bulb-type, fir-tree type, or dove-tail type roots. The blades are then locked by means of screws, spacers, pins, keys, lock wires. The clearance between rotating blades and the outer case is critical.

Rotor blades are thinner at the tips than at the base. This design helps prevent damage to the blade, stator vanes, or compressor housing if the blade contacts the compressor housing.
Compressor Components: Rotor Blades

Compressor rotor blades are shorter at the discharge than at the inlet.

This narrower working space is caused by the decrease in casing diameter, by the increase in rotor wheel diameter, or both.

Some compressor blades have knife-edge tips. At ambient temperature, the compressor rotor fits easily into the compressor case.

However, as the blades expand from compression heat, they lengthen and reduce clearance between the case and rotors.
Axial Flow Compressor components: Rotor Blades

Compressor Components: Rotor Blades

Tighter clearances increase the efficiency of the axial flow compressor.
Compressor Components: Stator

Stator vanes are the non-moving elements of the compressor. They are located between each rotor stage. Stator blades are attached to the inner wall of the case.

Stator vanes receive high velocity air from each preceding rotor stage of the compressor.

Stator vanes direct airflow to the next stage of compression at the desired angle.

This controlled direction provides increased blade efficiency.
Axial Flow Compressor components: Rotor Blades

- Stator vanes also act as diffusers, changing velocity to pressure.
- Stator vanes on the discharge end of the compressor are aligned to straighten the airflow and reduce turbulence.
- These vanes are called straightening vanes, outlet vane assemblies, or exit guide vanes.
Compressor Components: Stator Vanes

Stator vanes are usually made of corrosion-resistant and erosion-resistant steel.

They may be mounted to the engine case in several ways. For example:
They are frequently shrouded or enclosed by a suitable band for fastening purposes.
Axial Flow Compressor components: Stator Vanes

- The vanes may be welded into the shrouds.
- The shroud is secured to the inner wall of the compressor case.
- In some cases, individual blades are inserted into slots cut in the case.
- Each component plays an important role in compressor operation.
Axial Flow Compressor: Operation

When air enters the compressor through the air inlet, incoming air passes through the first row of vanes, called inlet guide vanes.

As the air enters the first set of rotating blades, it is deflected in the direction of blade rotation.

The air is then caught and turned as it passes through a set of stator vanes. From there, the air is picked up by another set of rotating blades.

This process continues through the compressor. The pressure of the air increases each time it passes through a rotor/stator blade set (called a stage).
As pressure is increased by successive rotor/stator blade sets, air volume is decreased.

At the compressor exit, the diffusion section finishes the compression process by decreasing air velocity and increasing pressure just before the air enters the combustion section.

A major effect of an unstable compression process is surging.
Compressor Surge

Compressor surge is a characteristic common to all types of gas turbines.

In general, surge is the result of unstable airflow in the compressor.

This unstable condition is often caused by air building up in the rear stages of the compressor.

When a compressor is not operating at its optimum speed, the forward compressor blades may provide more air than the downstream stages can compress. The air then tends to reverse flow. The compressor surges.
Surging causes the machine to vibrate excessively.

Several methods are used to control surging.

For example, the two-shaft gas turbine design reduces the possibility of surging.

Compressors with higher compression ratios have a greater tendency to surge.
Large, high-powered gas turbines require greater efficiency and higher compression than can be obtained with a single axial flow compressor.

Single axial compressors usually have a compression ratio of approximately 8:1.

Compression ratio is determined by the discharge pressure (psia) divided by the suction pressure (psia).

For example, a gas turbine with a compression ratio of 8:1 discharges 117.6 psia of discharge pressure for every 14.7 psia of suction pressure.

In two-shaft gas turbines, one or more turbine stages drive the compressor.
Two-Shaft Axial Flow Gas Turbine

A separate turbine section drives the compressor.

Except for the airflow, the two rotor systems (compressor and turbine) operate independently.

Each compressor is driven at its own speed by its own set of turbine wheels.
Two-shaft gas turbines use a coaxial rotor shaft. A coaxial shaft consists of a hollow outer shaft containing a solid inner shaft.

The inner shaft is mounted on bearings, which allows each shaft to independently rotate at different speeds.

The front compressor is the low pressure compressor. The rear compressor is the high pressure compressor.
Two-Shaft Compressor

Two-shaft compressors can operate with lower compression ratios. The lower compression ratio helps reduce the possibility of surging.

For example, if a gas turbine had a compression requirement of 20:1, a two-shaft (dual compressor) would share the load.

Each compressor, operating in series, may have only a 4:1 or 5:1 compression ratio. The net compression ratio of the dual compressors is higher than that of a single compressor.
For the dual-compressor engine, compressor pressure ratio is usually given for each compressor or as:

LP compressor 4:1
\[ \times \]
HP compressor 5:1

= Total compression of 20:1

The ratio of one compressor is multiplied by the other to give the total compressor pressure ratio.
Centrifugal (Radial) Compressor

Figure 23 - Operation of a centrifugal compressor.
Centrifugal (Radial) Compressor
These compressors take air in at the center or “eye” of the rotor.

Due to the high rotational speeds of the rotor, the air is accelerated by the blades and forced radially to the edge of the rotor at high velocity by centrifugal force.

There, the air is received by the diffuser, which in turn, converts the high velocity to pressure energy.

Advantages of the radial or centrifugal compressor are simplicity, strength and short length.
COMPRESSOR INLET AIR COOLING SYSTEMS:

- Continuous Cooling Systems
  - Open Cycle
    - Refrigerant Plant
  - Closed Cycle
    - Thermal Storage
    - Compression Plant
    - Absorption Plant
    - Ice Storage
    - Water Storage
- Evaporative Cooling Systems
  - Traditional Systems
    - High Pressure Fogging
  - Fogging
  - Ibrid Systems
    - Overspray
    - Interstage Fogging

Compressor inlet air cooling strategies
COMPRESSOR INLET AIR COOLING SYSTEMS:

Continuous cooling systems with compression refrigerant plant

Gas Turbine-COMPRESSOR

Dr. Walid Abdelghaffar
COMPRESSOR INLET AIR COOLING SYSTEMS:

Continuous cooling system with absorption refrigerant plant

Gas Turbine-COMPRESSOR  Dr. Walid Abdelghaffar
COMPRESSOR INLET AIR COOLING SYSTEMS:

Thermal energy storage with cold water
Gas Turbine-COMPRESSOR

Thermal energy storage with ice
Dr. Walid Abdelghaffar
Traditional evaporative cooler systems:

This system uses a wetted honeycomb media for water evaporation. The temperature drop that is possible to realize is a function of the equipment design on one hand, and of ambient conditions on the other hand. The effectiveness of the cooler is given by:

\[ E = \frac{T_a - T_{ac}}{T_a - T_{wb}} \]

Psychrometric chart for a traditional evaporative cooling system
Evaporative hybrid systems:

Evaporative cooling hybrid system scheme

Psychrometric chart for an evaporative cooling hybrid system
Fogging

Is a method where demineralized water is converted into a fog by means of special atomizing nozzles operating at high pressure (from 70 to 200 bar). The cooling effect is provided by water evaporation. This means that an adiabatic saturation of inlet air mass flow rate occurs in the gas turbine inlet duct. In Fig. 9 is presented a psychrometric chart showing the cooling potential of fogging approach. The effect of the adiabatic saturation is to cool the air from the dry bulb temperature (point $a$ in Fig. 9) to the wet bulb temperature (point $wb$ in Fig. 9). This means a value of cooling efficiency ($E$) close to 100%.

*Psychrometric chart (@ $p=1.01325$ bar)*
### Inlet air cooling technologies main characteristics

<table>
<thead>
<tr>
<th>Technology</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open cycle continuous cooling</td>
<td>- relatively easy to realize</td>
<td>- water source required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- additional pressure drop</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- cooling potential depends on climatic conditions</td>
</tr>
<tr>
<td>Continuous cooling with compression refrigerant plant</td>
<td>- provides an instantaneous cooling</td>
<td>- refrigerant fluid is required</td>
</tr>
<tr>
<td></td>
<td>- air could be cooled lower than wet bulb temperature</td>
<td>- high electrical power consumption (from the almost the same to a third more</td>
</tr>
<tr>
<td></td>
<td>- particularly effective when required power enhanced time is long (more than 6:8 hours/day)</td>
<td>than mechanical chilling) &amp; additional compressor inlet pressure drop</td>
</tr>
<tr>
<td></td>
<td>- not much floor space is required - using standard package chillers</td>
<td>- refrigerant leakage possible danger</td>
</tr>
<tr>
<td>Continuous cooling with absorption refrigerant plant</td>
<td>- provides an instantaneous cooling</td>
<td>- heat source (gas or steam etc.) is required</td>
</tr>
<tr>
<td></td>
<td>- air could be cooled lower than wet bulb temperature</td>
<td>- very hot gas (more than 650 °C) for a successfully application is needed (if heat</td>
</tr>
<tr>
<td></td>
<td>- particularly effective when required power enhanced time is long (more than 6:8 hours/day)</td>
<td>source is gas)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- need a steam cycle (if heat source is steam)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- power consumption</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- additional compressor inlet pressure drop</td>
</tr>
</tbody>
</table>
# COMPRESSOR INLET AIR COOLING SYSTEMS

## Inlet air cooling technologies main characteristics

| Continuous cooling with Thermal energy Storage | -particularly effective when power enhanced is required for few hours a day  
-relevant temperature reduction  
-particularly effective when the difference in economic value between peak and non-peak hours is high | -complex installation  
-energy consumption for cold source maintenance is required  
-additional compressor inlet pressure drop |
|---|---|---|
| Conventional evaporative cooling | -relatively inexpensive to install  
-easy to control | -is not possible to reach 100 % of relative humidity  
-inadequate for application in high humidity regions  
-demineralized water consumption  
-additional compressor inlet pressure drop |
| Hybrid systems | - additional cooling on the respect of the wet bulb temperature | -extremely complex  
-water or other refrigerant fluid is required  
-quite expensive |
### COMPRESSOR INLET AIR COOLING SYSTEMS:

**Inlet air cooling technologies main characteristics**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>High pressure fogging</td>
<td>- quite inexpensive&lt;br&gt;- minimum plant modifications required&lt;br&gt;- minimum additional compressor inlet pressure drop</td>
<td>- demineralized water consumption&lt;br&gt;- impossible to cool air lower than wet bulb temperature&lt;br&gt;- not much effective for high humidity regions application</td>
</tr>
<tr>
<td>Overspray fogging</td>
<td>- quite inexpensive&lt;br&gt;- minimum plant modifications required&lt;br&gt;- minimum additional compressor inlet pressure drop&lt;br&gt;- additional power boost respect to inlet fogging</td>
<td>- demineralized water consumption&lt;br&gt;- impossible to cool air lower than wet bulb temperature&lt;br&gt;- not much effective for high humidity regions application&lt;br&gt;- possible compressor blades erosion</td>
</tr>
<tr>
<td>Interstage injection</td>
<td>- compressor cleanness and efficiency</td>
<td>- compressor modification required&lt;br&gt;- hard to realize as retrofit option&lt;br&gt;- possible compressor blades erosion danger</td>
</tr>
</tbody>
</table>
Gas Turbine-COMPRESSOR

Dr. Walid Abdelghaffar