CHAPTER 3:
AIR COMPRESSOR

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Learning Objectives

- Identify types of compressors available
- Calculate air capacity rating of compressor
- Design the sizing of air receivers
- Calculate power required to drive compressors
3.1 Introduction

- A compressor is a machine that compresses air or another type of gas from a low inlet pressure to a higher desired pressure level.
- This is accomplished by reducing the volume of the gas.
3.2 Type of Compressor

- Compressor can be divided into two main groups as illustrated in Figure 3.1.
Positive Displacement Compressor

- A Displacement Machine or Positive Displacement Compressor consists of a movable member inside housing.

- The compressor has a piston for a movable member.

- The piston is connected to a crankshaft, which is in turn connected to a prime mover (electric motor, internal combustion engine).

- At inlet and outlet ports, valves allow air to enter and exit the chamber.

- It can be divided into 2 categories such as
  1) Reciprocating Compressors and,
  2) Rotary Compressors.
Reciprocating Compressors.

There are two types of reciprocating compressor such as Single Stage Reciprocating Compressor and Multi-Stage Reciprocating Compressor

a) *Single stage reciprocating compressor*,
air is drawn in through the input valve during the intake stroke and compressed during the compression stroke and after reaching the correct pressure, is expelled through the exhaust valve

b) *Multi-stage reciprocating compressor*,
Smaller pressure difference is chosen and the air is cooled between stages that removes a significant portion of the heat of compression.
This increases air density and the volumetric efficiency of the compressor.
Reciprocating Compressors.

Figure 3.2 Single Stage Reciprocating Compressor

Figure 3.3 Multi-Stage Reciprocating Compressors
Figure 3.4 : Two stage Compressor
Table 3.1: Effect of number of stages on pressure capacity

<table>
<thead>
<tr>
<th>Number of stages</th>
<th>Pressure capacity (PSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>150</td>
</tr>
<tr>
<td>2</td>
<td>500</td>
</tr>
<tr>
<td>3</td>
<td>2500</td>
</tr>
<tr>
<td>4</td>
<td>5000</td>
</tr>
</tbody>
</table>
Screw Compressor

- Screw-type Compressor are rotary compressors with two shafts.
- It stronger and better manufacturing process.
- They work according to the displacement principle and deliver a continuous supply with no pulsations of pressure fluctuations.
- Compression is accomplished by rolling the trapped air into a progressively smaller volume as the screw rotate.
- Screw-type compressors can be built as non-lubricated devices for the supply of oil free compressed air.

Figure 3.5 Screw-type Compressor
Rotary screw compressor.
Small rotary screw compressor.
(Photo courtesy of Ingersoll-Rand Company.)

Large, enclosed rotary screw compressor.
(Photo courtesy of Ingersoll-Rand Company.)

Figure 3.6 Rotary Screw Compressor
Vane Compressor

- As the rotor rotates, centrifugal force holds the vanes in contact with the stator wall and the space between the adjacent blades decreases from air inlet to outlet, so compressing the air.

Figure 3.7 Sliding Vane Compressors
3.3 Air capacity rating of Compressor

- Air compressor are generally rated in terms of cfm of free air, defined as air at actual atmospheric conditions.
- SCFM is standard cubic feet per minutes (14.7 psia/101 KPa abs and 68° F/20°C).

\[
Q_1 = Q_2 \left( \frac{P_2}{P_1} \right) \left( \frac{T_1}{T_2} \right)
\]

where 1 represents compressor inlet atmospheric conditions, 2 represents compressor discharge conditions.
Example 1

• Air is used at a rate of 30 cfm from a receiver at 90°F and 125 psi. If the atmospheric pressure is 14.7 psia and the atmospheric temperature is 70°F, how many cfm of free air must the compressor provide?

Solution;

\[
Q_1 = Q_2 \left( \frac{P_2}{P_1} \right) \left( \frac{T_1}{T_2} \right)
\]

\[
Q_1 = 30 \times \left( \frac{125 + 14.7}{14.7} \right) \left( \frac{70 + 460}{90 + 460} \right)
\]

\[
= 275 \text{ cfm of free air}
\]

The compressor must receive atmospheric pressure (14.7 psia, 70°F) at a rate of 275 cfm in order to deliver air (125 psi, 90°F) at 30 cfm.
Exercise

- Air is used at a rate of 45 cfm from a receiver at 105°F and 125 psi. If the atmospheric pressure is 14.7 psia and the atmospheric temperature is 60°F, how many cfm of free air must the compressor provide?

Solution:

\[ Q_1 = Q_2 \left( \frac{P_2}{P_1} \right) \left( \frac{T_1}{T_2} \right) \]
3.4 Sizing of Air Receivers

- A receiver is an air reservoir.
- Its function is to supply air at essentially constant pressure.
- It also serves to dampen pressure pulse either coming from the compressor or the pneumatic system during valve shifting and component operation.
- There are several parameters need to take into account:
  1. system pressure,
  2. flow rate requirements,
  3. compressor output capability,
  4. the type of duty of operation.
The below equations can be used to determine the proper size of the receiver

\[ V_r = \frac{14.7t(Q_r - Q_c)}{P_{\text{max}} - P_{\text{min}}} \]  
\[ V_r = \frac{101t(Q_r - Q_c)}{P_{\text{max}} - P_{\text{min}}} \]

**English units**

**Metric Units**

t  = time that receiver can supply required amount of air (minute)
Qr  = consumption rate of pneumatic system (scfm, standard m³/min)
Qc  = output flow rate of compressor (scfm, standard m³/min)
Pmax  = max pressure level in receiver (psi, KPa)
Pmin  = min pressure level in receiver (psi, KPa)
Vr  = receiver size (ft³, m³)
Example 2

- Calculate the required size of a receiver that must supply air to a pneumatic system consuming 20 scfm for 6 min between 100 and 80 psi before the compressor resumes operation.

**Solution:**

\[ V_r = \frac{14.7t(Q_r - Q_c)}{P_{\text{max}} - P_{\text{min}}} \]

\[ V_r = \frac{14.7 \times 6(20 - 0)}{100 - 80} = 88.2 \text{ ft}^3 \]

It is common practice to increase the calculated size of the receiver by 25% for unexpected overloads and by another 25% for possible future expansion needs.
Exercise

- Calculate the required size of a receiver that must supply air to a pneumatic system consuming 30 scfm for 5 min between 100 and 75 psi before the compressor resumes operation.

Solution;

\[ V_r = \frac{14.7t(Q_r - Q_c)}{P_{\text{max}} - P_{\text{min}}} \]
The objective of this design consideration is to meet system pressure and flow rate requirements.

The below equations can be used to determine the theoretical power required to drive an air compressor.

\[
\text{Theoretical horsepower (HP)} = \frac{P_{in}Q}{65.4} \left[ \left( \frac{P_{out}}{P_{in}} \right)^{0.286} - 1 \right]
\]

\[
\text{Theoretical power (KW)} = \frac{P_{in}Q}{17.1} \left[ \left( \frac{P_{out}}{P_{in}} \right)^{0.286} - 1 \right]
\]

Where, \( P_{in} \) = inlet atmospheric pressure (psia, KPa abs)
\( P_{out} \) = outlet pressure (psia, Kpa abs)
\( Q \) = flow rate (scfm, standard m\(^3\)/min)
Example 3

Determine the actual power require to drive a compressor that delivers 100 scfm of air at 100 psig. The overall efficiency of the compressor is 75%.

Solution:

\[
\text{Theoretical horsepower (HP)} = \frac{P_{\text{in}}Q}{65.4} \left( \frac{P_{\text{out}}}{P_{\text{in}}} \right)^{0.286} - 1
\]

\[
HP_{\text{theory}} = \frac{14.7 \times 100}{65.4} \left[ \left( \frac{114.7}{14.7} \right)^{0.286} - 1 \right] = 18.0 \text{hp}
\]

\[
HP_{\text{actual}} = \frac{HP_{\text{theory}}}{\eta_{\text{overall}}} = \frac{18.0}{0.75} = 24.0 \text{hp}
\]
Example 3

Determine the actual power require to drive a compressor that delivers 120 scfm of air at 90 psig. The overall efficiency of the compressor is 80%.

Solution:

\[
\text{Theoretical horsepower (HP)} = \frac{P_{in} Q}{65.4} \left[ \left( \frac{P_{out}}{P_{in}} \right)^{0.286} - 1 \right]
\]
Summary

Upon completing this topic, you should know:

- The types of compressors
- How to design components of a compressor
Most pressure gauges on equipment read relative pressure. When an air compressor is off and empty the pressure gauge on it reads zero - but if it's at sea level the air pressure in it is actually about 14.5 psi. So, the zero is relative and when you pump the compressor up to 100 psi on the gauge the actual pressure in the tank is about 114.5.

Ronald L. Klaus, did a PhD thesis in the area of thermodynamics
Witten 15 Jul

The Rankine temperature scale is an absolute temperature scale, i.e., degrees above absolute zero, that is related to the Fahrenheit scale in much the same way that the Kelvin scale (absolute) is related to the Centigrade scale. Fahrenheit temperatures are commonly used in engineering calculations especially in the USA and the United Kingdom. Certain calculations require the use of absolute temperatures, i.e., temperatures above absolute zero and in such engineering calculations it is convenient to use the Rankine scale. Zero degrees Rankine is equivalent to -459.67 degrees Fahrenheit.

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Wendy Krieger, studies measurement for designing a measurement system
Witten 29 Jul

The rankine scale is used wherever an absolute scale in Fahrenheit units are required.

In the formula, PV=NRT (the universal gas law), T is measured in absolute units, where 0 is -273.16 C = -459.67 F. If T is measured regularly in Fahrenheit, then Tα is measured in rankine. If T is met in centigrade, then Tα is met in kelvins.