Improving Compressed Air System Performance

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Module 1. Introduction to Industrial Compressed Air Systems

Learning Objectives

By the end of this section, you will be able to:

- **Identify** the major sub-systems and components of an industrial compressed air system and their specific roles in air production and distribution.
- **Evaluate** the mechanical and operational differences between positive-displacement and dynamic compressors to select the optimal technology for a given load profile.
- **Select** appropriate air treatment accessories, such as dryers and filters, to meet specific pressure dew point and air quality requirements.

Executive Summary: Often referred to as the "fourth utility," compressed air is vital to industrial operations but is highly energy-intensive. Properly managing both the supply side (generation) and the demand side (distribution and end-use) can yield energy savings of 20 to 50 percent, translating to significant annual cost reductions and improved product quality.

Components of an Industrial Compressed Air System

A modern industrial compressed air system is composed of several major sub-systems and many sub-components. These include the compressor, prime mover, controls, treatment equipment, and the distribution system.

- **Compressor:** The mechanical device that takes in ambient air and increases its pressure.
- **Prime Mover:** Powers the compressor, most commonly an electric motor.
- **Controls:** Regulate the amount of compressed air being produced to match system demand.
- **Treatment Equipment:** Removes contaminants such as dirt, lubricant, and water from the air.
- **Distribution Systems:** Transport compressed air to where it is needed, analogous to electrical wiring.

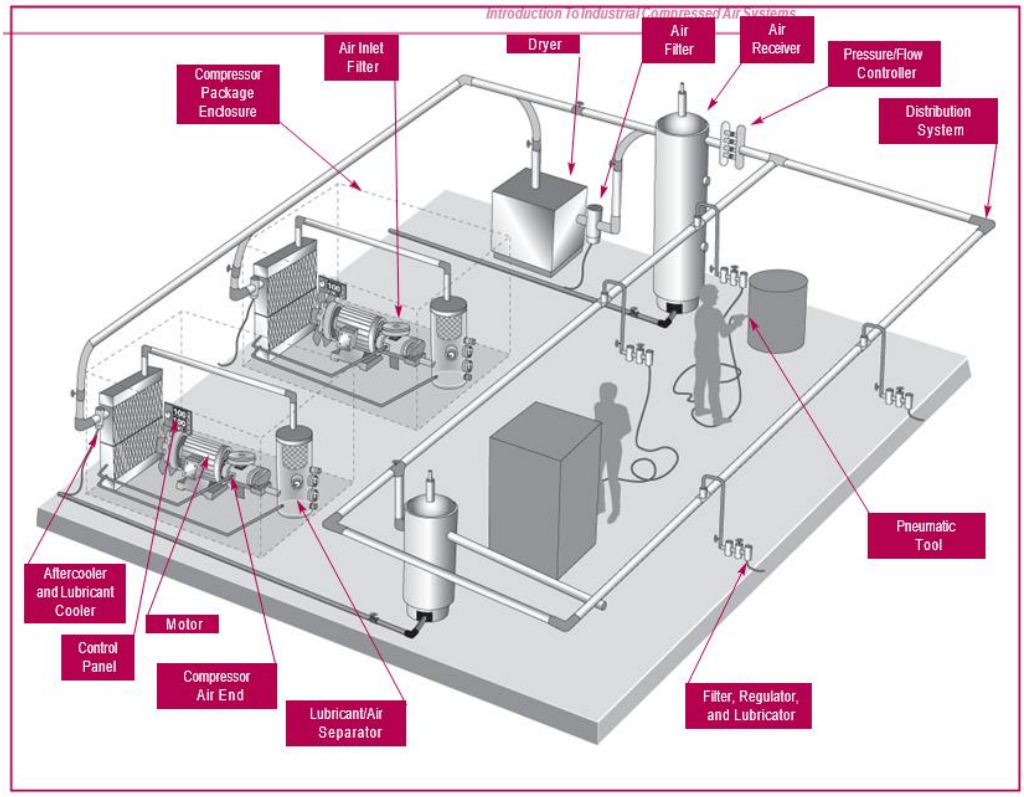

Figure 1.1 Components of a Typical Industrial Compressed Air System.

Compressor Types

Industrial air compressors are often sold as "packaged" units for ease of installation. As shown in Figure 1.2, there are two basic compressor types: **positive-displacement** and **dynamic**.

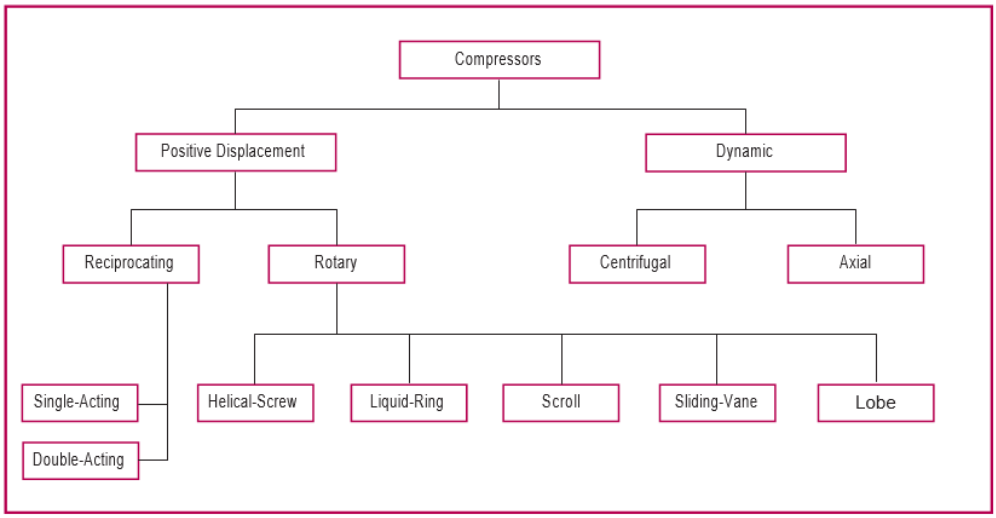

Figure 1.2 Compressor Family Tree.

Positive-Displacement Compressors

In positive-displacement types, a given quantity of air is trapped in a compression chamber and the volume is mechanically reduced.

- **Reciprocating:** Functions similarly to a bicycle pump using a piston. Single-acting units compress in one direction; double-acting units provide a compression stroke in both directions.
- **Rotary:** These use intermeshing rotors to trap and compress air. The **rotary screw** is the most common industrial "workhorse" in the 30 to 200 hp range.

Single-Acting, Reciprocating Air Compressors

This type is characterized by an automotive-type piston. Compression takes place on the top side of the piston.

- **Configurations:** Available as air-cooled or liquid-cooled, and as single-stage (25 to 125 psig) or two-stage (125 to 175 psig).
- **Lubrication:** Available in lubricated, lubricant-free (using self-lubricating materials), or lubricant-less (grease pre-packed bearings) designs.
- **Drives:** Most commonly belt-driven, though flange-mounted or direct-coupled drives are used for compactness.

💡 **Design Tip:** Use two-stage or multi-stage designs with inter-stage cooling to reduce discharge temperatures, which improves both efficiency and equipment durability.

Double-Acting, Reciprocating Air Compressors

These units use both sides of the piston for compression, doubling the capacity for a given cylinder size.

- **Efficiency:** Relatively slow operating speeds and water-cooled intercooling result in excellent compression efficiency.
- **Maintenance:** Cylinder lubrication is typically handled by a forced-fed lubricator at a rate of several drops per minute.
- **Balance:** Typically require a substantial foundation due to unbalanced reciprocating forces.

Lubricant-Injected Rotary Screw Compressors

This has become a dominant industrial compressor type. It consists of two intermeshing helical rotors (male and female) in a stator housing.

- **Lubricant Functions:** Lubricates rotors/bearings, removes heat of compression, and acts as a seal.
- **Separation:** A sump/separator and coalescing filter remove lubricant from the air, resulting in carry-over of only 2 to 5 ppm.
- **Cooling:** Usually involves an aftercooler and moisture separator. Air-cooled radiator types allow for heat recovery for facility heating.

Lubricant-Free Rotary Screw Compressors

- **Dry-type:** Intermeshing rotors do not touch and are maintained by timing gears. Usually requires two stages with intercooling.
- **Water-injected:** Water is injected into the chamber to act as a seal and heat remover, allowing pressures of 100 to 150 psig in a single stage.

Dynamic Compressors

These raise pressure by imparting velocity energy and converting it to pressure energy.

- **Centrifugal:** Most common dynamic type. It uses high-speed impellers and a diffuser/volute to convert velocity to pressure.
- **Axial:** Restricted to very high flow capacities; uses multiple rows of rotating blades and stationary vanes.

Centrifugal Air Compressors

Centrifugal units have a continuously flowing air stream with impellers rotating at speeds exceeding 50,000 rpm.

- **Performance:** As system pressure decreases, flow capacity increases. Capacity increases as ambient temperature decreases (increased air density).
- **Control:** Regulated via inlet throttle valves or guide vanes. Reduction in flow is limited by **surge**, a flow reversal phenomenon.

⚠️ **Safety Constraint:** Shaft vibration monitoring is mandated for centrifugal compressors to record operational trends and protect high-speed rotating components from damage.

Compressor Prime Movers

- **Electric Motors:** Most common. Premium-efficient motors are recommended as the cost is typically recovered quickly through energy savings.
- **Engines:** Diesel or natural gas engines are used in specific industries or for emergency standby.
- **Steam Turbines:** Used primarily when steam is readily and inexpensively available within the plant.

Compressed Air System Controls

Controls match compressor supply with system demand.

- **Network Controls:** Link on-board microprocessors to coordinate multiple compressors.
- **System Master Controls:** Optimize the entire system, providing data trending and centralized management.

Accessories

Accessories treat air and ensure smooth system delivery.

- **Air Inlet Filters:** Protect the compressor from atmospheric particles.
- **Intercoolers/Aftercoolers:** Remove heat of compression and condense water vapor.
- **Separators:** Devices that remove entrained liquids following coolers.
- **Dryers:** Prevent condensation in distribution piping.
    - **Refrigerant:** Lowers dew point to ~35°F.
    - **Regenerative-Desiccant:** Uses porous material for very low dew points (e.g., -40°F).
    - **Deliquescent:** Uses a chemical medium that is consumed during the process.
    - **Heat-of-Compression:** Uses compression heat to regenerate desiccant.
    - **Membrane:** Uses semi-permeable membranes for dew point suppression.

Calculation Note: In general, reducing the temperature of saturated compressed air by 20°F will reduce the moisture content by approximately 50%.

- **Filters:** Include particulate, coalescing (for lubricant removal), and adsorbent types.
- **Heat Recovery:** More than 80% of electrical energy to a compressor becomes available as recoverable heat for water or space heating.
- **Air Receivers:** Provide storage to meet peak demands and help stabilize system pressure.
- **Traps and Drains:** Crucial for removing condensate; zero air-loss traps are the most efficient method.

Air Distribution Systems

The distribution system should deliver air with minimal pressure loss.

- **Layout:** A loop system is generally recommended.
- **Slope:** Headers should slope away from the compressor toward drop legs.
- **Connections:** Point-of-use piping should connect to the **top or side** of the header to avoid condensate contamination.

Uses of Compressed Air

Industrial uses include powering pneumatic tools, automation, and process operations like oxidation and aeration.

Purchase this course to see the remainder of the technical materials.