Improving Fan System Performance

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Module 1: Introduction to Fan Systems

Learning Objectives

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

- **Identify** the primary performance differences between centrifugal and axial fan types.
- **Evaluate** the operational impacts of over-specifying fan capacity on system reliability and efficiency.
- **Calculate** fan efficiency and performance changes using fundamental fan laws and pressure loss equations.

Executive Summary: Successful fan system management requires a "systems approach" that focuses on total system performance rather than individual components. Over-specifying fan capacity to compensate for design uncertainties leads to inefficient operation, unstable performance, and increased maintenance costs.

Fan System Fundamentals

Fans are critical for process support and human health in industrial and commercial applications. In the manufacturing sector, fans use approximately **78.7 billion kilowatt-hours** of energy each year, representing **15 percent** of the electricity used by motors. In the commercial sector, fan motors compose a large portion of energy costs for space conditioning.

Performance ranges from **"free air"** to several **pounds per square inch gage (psig)**, with airflow from a few cubic feet per minute (cfm) to more than **1 million cfm**.

⚠️ **Safety Constraint:** Pressures above **15-psig** generally require air compressors; these are addressed in separate specialized courses.

Reliability and the Cost of Oversizing

In manufacturing, fan reliability is critical. Fan failure in material handling or industrial ventilation often forces immediate process stoppages. This criticality often leads designers to be conservative, adding excess capacity to fans to compensate for uncertainties.

Consequences of Oversized Fans

- **Efficiency Loss:** They do not operate at their **best efficiency points (BEP)**.
- **Instability:** Fans may operate in an unstable manner on the airflow-pressure curve.
- **System Stress:** Excess flow energy results in high noise and increased mechanical stress.

Fan Classifications

There are two primary types of fans, characterized by the path of the airflow through the fan:

Centrifugal Fans

- **Mechanism:** Use a rotating impeller to increase airstream velocity. Kinetic energy is converted to static pressure as air slows before discharge.
- **Applications:** Capable of generating high pressures. Frequently used in **"dirty" airstreams** (high moisture/particulates), material handling, and high-temperature systems.

Axial Fans

- **Mechanism:** Move air along the axis of the fan using aerodynamic lift generated by blades, similar to a propeller.
- **Applications:** Commonly used in **"clean air,"** low-pressure, high-volume applications.
- **Comparison:** They have less rotating mass and are more compact than centrifugal fans but tend to have higher rotational speeds and higher-frequency noise.

Fan Selection Factors

Fan selection is a complex process starting with a basic knowledge of system operating requirements: airflow rates, temperatures, pressures, and layout.

- **Noise:** Depends on fan type, flow rate, and pressure. If high noise is unavoidable, use duct insulation, soft mounting (rubber/spring isolators), or sound-damping baffles.
- **Rotational Speed (RPM):** Speed has a significant impact on performance. High-temperature applications often require lower speeds because materials exhibit lower yield strengths at heat.
- **Airstream Characteristics:** * **Contaminants:** Backward-inclined fans are susceptible to build-up; radial tip and radial blade fans are better for "dirty" air.
    - **Corrosion:** Requires expensive alloys or fiberglass-reinforced plastic coatings.
    - **Flammability:** Requires nonferrous alloys and proper grounding to minimize spark risks.
- **Space and Structural Constraints:** Foundation and structural support depend on fan size and weight. Compact fans free up floor space but elbows placed too close to inlets/outlets can create a costly **system effect**.

Fan Performance Curves

Performance is defined by a plot of developed pressure and power required over a range of airflow.

Best Efficiency Point (BEP)

Fan efficiency is the ratio of power imparted to the airstream to power delivered by the motor.

Equation 1-1: Total Efficiency

$$\text{Total Efficiency} = \frac{\text{Total Pressure} \times \text{Airflow}}{\text{bhp} \times 6{,}362}$$

Where:

- **Total Pressure** = inches of water
- **Airflow** = cubic feet per minute (cfm)
- **bhp** = brake horsepower

Region of Instability

Most fans have an operating region where the curve slopes in the same direction as system resistance.

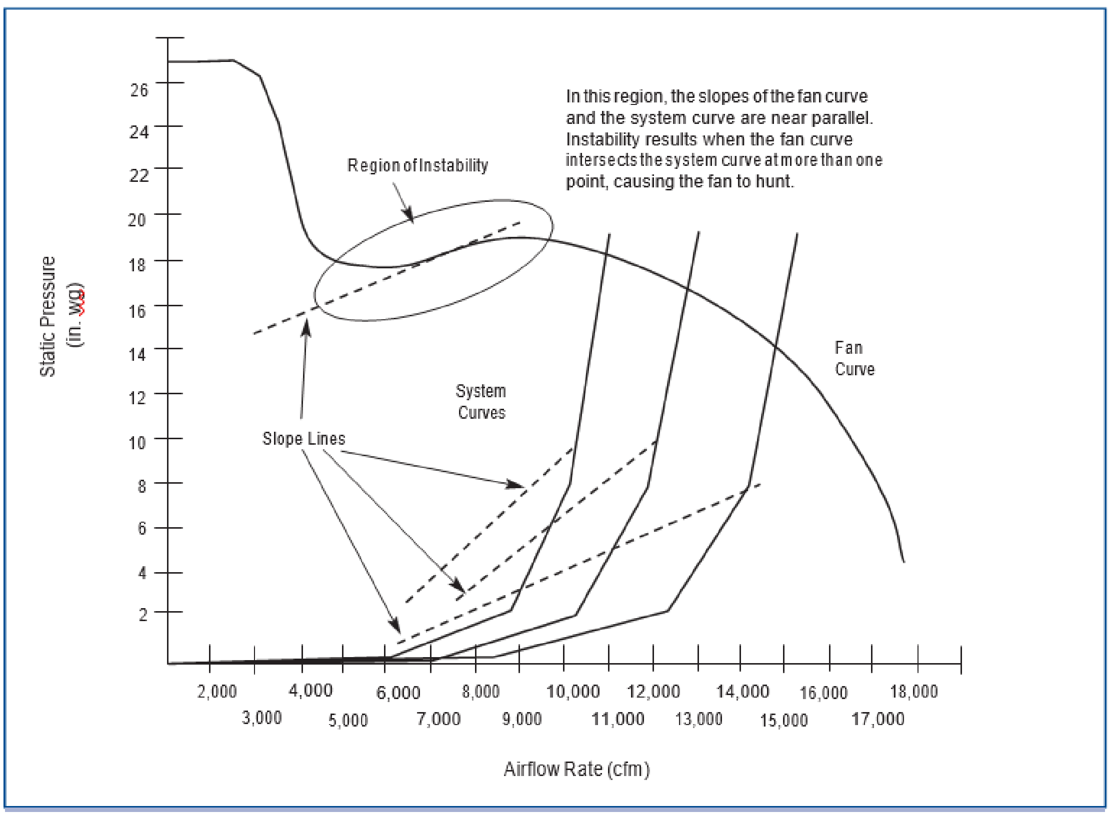

Figure 1-1: Region of Instability

Fan Start-Up

- **Commissioning:** Ensuring proper installation, alignment, and fit-up.
- **Acceleration:** Centrifugal fans have large rotational inertia (**WR2**).
- **Load Management:** Centrifugal fans should start with downstream dampers **closed**; axial fans should start with them **open**.
- **Soft Starters/VFDs:** These technologies allow gradual acceleration and reduce starting current to **1.5 to 2 times** the operating current.

System Effect

The system effect is the change in performance resulting from the interaction of system components.

Equation 1-2: Pressure Loss

$$\Delta p = C \times \left(\frac{V}{1{,}097}\right)^2 \times \rho$$

Where:

- **Δp** = pressure loss (in. wg)
- **C** = loss coefficient
- **V** = velocity (ft/min)
- **ρ** = density (0.075 lb/ft3 at standard conditions)

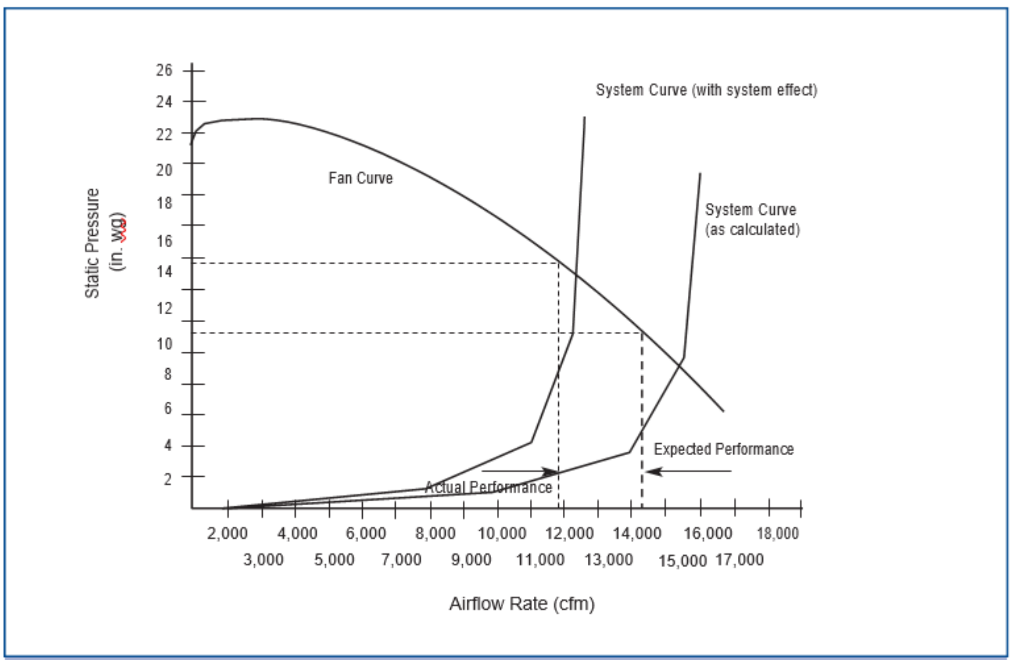

Figure 1-2: System Effect for a Typical Fan and System

Fan System Components

A typical fan system consists of a fan, an electric motor, a drive system, ducts/piping, flow control devices, and air conditioning equipment.

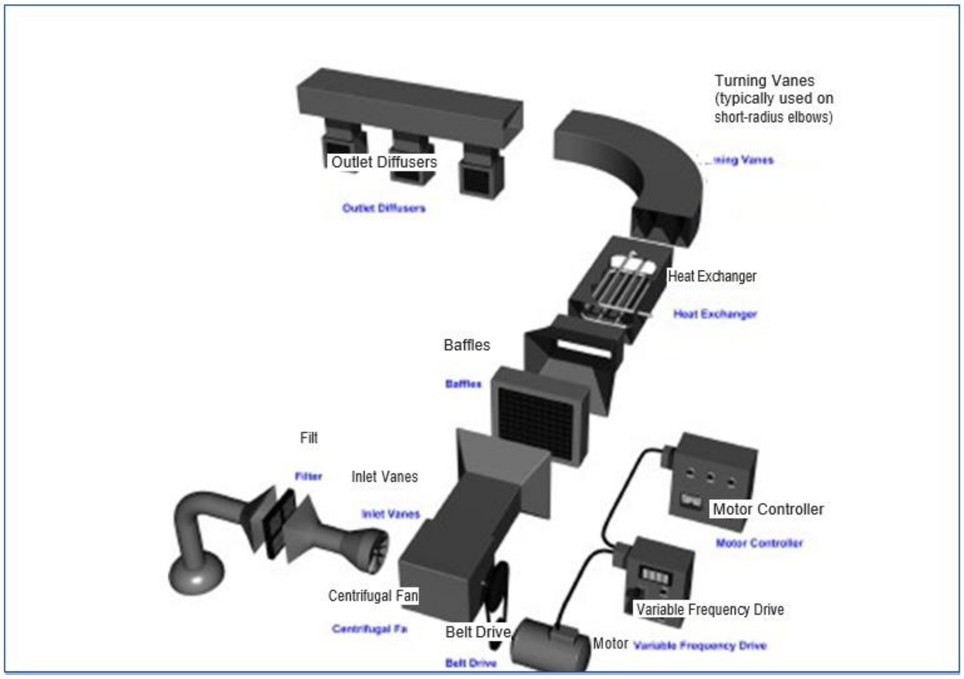

Figure 1-3: Typical Fan System Components

- **Prime Movers:** Most fans use three-phase AC induction motors. EPAct-efficiency motors operate with less **slip**, meaning fans rotate at slightly higher speeds.
- **Drive System:**
  - **Direct Drive:** Simple and efficient but lacks speed flexibility.
  - **Belt Drive:** Allows speed selection by altering pulley diameters. **V-belts** are common and provide drivetrain protection; **synchronous belts** are more efficient but noisier.
- **Ductwork/Piping:** Round ducts have less surface area and less leakage than rectangular ducts.
- **Airflow Control Devices:**
  - **Inlet Vanes:** Create pre-rotation swirls to reduce brake horsepower.
  - **Outlet Dampers:** Adjust resistance but do not offer energy savings other than shifting the operating point.
  - **Variable Pitch Blades:** Highly efficient for axial fans.
  - **VFDs:** Generally the most efficient method for continuous speed adjustment.