The System Curve, the Fan Curve, and the Operating Point

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Keith D. Robinson, P.E.
Overall Objective

• To equip an Industrial Hygienist with the skills necessary to document the performance of the Industrial Ventilation (IV) systems within their facilities without the need of outside personnel.
Learning Objectives

• Understand the concept of the duct system curve and the fan curve.
• Demonstrate the interaction between the system curve and the fan curve, the operating point.
• Apply the concept of the Operating point to develop simple IV system monitoring tools, procedures, and systems.
Example Industrial Ventilation System
Example Industrial Ventilation System
Example Industrial Ventilation System

Common Questions:
Is the system still operating as designed?
What is the flow at each hood?
What is the capture velocity at the hood face?
The System Curve
System Curve

• Assume you have a fan with a fixed duct system. An adjustable damper is installed in the ductwork upstream of the fan.
System Curve

- Fluid flow is either *laminar* or *turbulent*.
- In *laminar* system the pressure drop is linearly related to velocity.
- In *turbulent* systems the pressure drop is a function of the velocity squared.
- Most air systems are turbulent.
System Curve

\[ P = K \cdot Q^2 \]
System Curve

What happens if we adjust the position of the control dampers in the system?
System Curve

Design System Curve

% of Shut Off Pressure

% of Wide Open Flow

- Design (Full Open)
- 75% Open
- 50% Open
- 25% Open
System Curve Summary

• Air system are typically turbulent.
• The pressure is related to the square of the velocity.
• A fixed duct system has one and only one system curve.
• Changing something in the ductwork creates a new duct system with a new system curve.
The Fan Curve
Fan Curve

There are many types of fans. The types that are typically used in IV systems are:

• Centrifugal
  – Backward inclined
  – Radial blade

• Axial
Fan Curve

As the fan impeller rotates, it imparts energy into an airstream. This energy can be seen in:

• Pressure
• Air movement (flow)
• Heat

The relationship between the amount of flow and the amount of pressure created by a rotating fan is called the “fan curve.”

The fan curve for each type of fan has a different shape.
Fan Curve
Fan Curve

Normalized Fan Curve for BI Fan

% of Shut Off Pressure

% of Wide Open Flow

0 10 20 30 40 50 60 70 80 90 100

0 10 20 30 40 50 60 70 80 90 100

120 110 100 90 80 70 60 50 40 30 20 10 0
Fan Laws

Flow

\[ CFM_2 = CFM_1 \cdot \frac{RPM_2}{RPM_1} \]

Pressure

\[ P_2 = P_1 \cdot \left( \frac{RPM_2}{RPM_1} \right)^2 \]

Horsepower

\[ HP_2 = HP_1 \cdot \left( \frac{RPM_2}{RPM_1} \right)^3 \]
Fan Law Example

• If you decrease the speed of a fan by 50%:
  – The new flow rate is 50% of the original flow rate.
  – The new pressure is 25% of the original pressure.
  – The horsepower is 12.5% of the original horsepower.

• If you increase the speed of a fan by 10%:
  – The new flow rate is 110% of the original flow rate.
  – The new pressure is 121% of the original pressure.
  – The horsepower is 133% of the original horsepower.
Fan Curve

Normalized Fan Curve for BI Fan

- RPM
- 60% RPM
- 80% RPM
- 90% RPM
- 110% RPM

% of Shut Off Pressure vs. % of Wide Open Flow
Fan Curve Density Effects

If the density of the air changes:

- The flow rate is not affected.
- The change in pressure is proportional to the change in density.
- The change in power is proportional to the change in density.
Fan Curve Density Effects

Fan curves are developed for air at normal conditions (14.7 psi, 70°F).
This means the fan curves are incorrect when used in locations whose elevation is above 1,000 ft. i.e. all locations in Colorado, Utah, and Wyoming.
Make sure fan curves are corrected for elevation.
Fan Curve Summary

• Fan curves are typically generated per ANSI/AMCA-210 (ASHRAE 51).
• Each fan model has a specific fan curve.
• The fan curve is a function of fan speed and air density.
• Make sure your fan curves are corrected for elevation.
Review

• The system curve represents the performance of a duct system. It shows the relationship between the flow rate and the pressure required to create that flow through the duct system.

• The fan curve represents the performance of a fan. It shows the relationship between the flow rate and pressure created by the rotation of a fan impeller.
The Operating Point
Operating Point

• The system curve governs the operation of the duct system.
• The fan curve governs the operation of the fan.
• The interaction of these two curves determine the operating point for the system.
Operating Point

![Design System Curve Graph]

- X-axis: % of Wide Open Flow
- Y-axis: % of Shut Off Pressure
- Graph shows the relationship between % of Wide Open Flow and % of Shut Off Pressure.
Operating Point

Normalized Fan Curve for BI Fan

% of Shut Off Pressure

% of Wide Open Flow
Operating Point

Design System Curve

Operating Point

Design Fan Curve
Design System Curve

% of Shut Off Pressure vs. % of Wide Open Flow
Operating Point

Design System Curve

- Design (Full Open)
- 75% Open
- 50% Open
- 25% Open

% of Shut Off Pressure vs. % of Wide Open Flow
Operating Point

Normalized Fan Curve for Blower

- RPM
- 60% RPM
- 80% RPM
- 90% RPM
- 110% RPM
- Design (Full Open)
- 75% Open
- 50% Open
- 25% Open

% of Shut Off Pressure

% of Wide Open Flow
Review

• The system will operate at the intersection of the system curve and the fan curve.
• A change in the system curve, i.e. a change in the pressure drop, will change the operating point.
• A change in fan speed will change the operating point.
So how is knowing this helpful in real life?
Application

Remember these rules:

• In a fixed duct system the system curve is fixed.

• Once you have determined the system curve, the flow in the branch can be known with a single pressure measurement.

• Data from the original test & balance report provides system curve.
Application

• If the operating point (flow rate & pressure) changes then either the fan curve or the system curve has changed.
Application

Double Drum Hood (Fixed slots, no damper within the hood) = \textit{Fixed system curve}

The pressure at this location is a function of flow. MEASURE PRESSURE HERE.
Application

What if an adjustable damper is in the duct?
Application

What if an adjustable damper is in the duct?

The pressure at this location is a function of flow AND damper position. **DO NOT MEASURE PRESSURE HERE UNLESS DAMPER IS LOCKED.**

The pressure at this location is a function of flow. **MEASURE PRESSURE HERE.**
Application

• A simple pressure gauge can be mounted to the hood/duct or near the hood/duct to provide a permanent real time performance monitor.

• There are many inexpensive commercially available pressure gauges.

• Many include options for upper and lower indicator flags or colored overlays for the face to indicate acceptable operating range.
Application

Approximate Installed Costs:
Differential Pressure Gauge (basic): $100
Mounting & Tubing: $  50
Installation (2 hrs. @ $75/hr.): $150
Approximate Total: $300
Application

• Write a Standard Operating Procedure or startup checklist that includes acceptable pressure range for each hood.
• If the hood pressure changes then either the fan curve or the system curve has changed.
• Maintenance or EH&S should be notified if pressure is outside of acceptable range.
Summary

- The system curve governs the operation of the duct system.
- The fan curve governs the operation of the fan.
- The interaction of these two curves determine the operating point for the system.
- Hood operation can be determined and documented with a single pressure measurement.
Summary

• Simple pressure gauges can provide:
  – Permanent real time performance monitoring
  – Document system performance
  – Facilitate system troubleshooting process