Better Plants
U.S. DEPARTMENT OF ENERGY

Industrial Fan Systems
Virtual INPLT Training & Assessment

Session 3

Fan Virtual INPLT Facilitator

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- Oak Ridge National Laboratory
- United Nations Industrial Development Organization
- Air Movement and Control Association, AMCA International
- Many industrial clients – both in the US and internationally

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Agenda – Session 3

- Welcome and Introductions
- Safety and Housekeeping
- Agenda for Fan System Virtual INPLT (8 weeks)
- Today's Content:

  Industrial Fan Systems Fundamentals
  - Fan affinity laws
  - Fan system controls

  MEASUR Tool
  - Demonstration
- Kahoot Quiz Game
- Q&A

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Better Buildings is an initiative of the U.S. Department of Energy

Safety and Housekeeping

- Safety Moment
  - A blockage in a fan system might be enough to put the fan into surge. Fans operating in surge can experience intense vibrations and pulsations that can cause structural failure of the impeller.
  - Accidents can be life-threatening
- You are welcome to ask questions at any time during the webinar
- When you are not asking a question, please MUTE your mic and this will provide the best sound quality for all participants
- We will be recording all these webinars and by staying on-line and a the meeting you are giving your consent to be recorded
  - A link to the recorded webinars will be provided, afterwards

Fan system Virtual INPLT Agenda

- Week 1 – Industrial Fan Systems Fundamentals and Introduction to MEASUR
- Week 2 – Fan and system curves, Fan types
- **Week 3 – Fan affinity laws, Fan system controls**
- Week 4 – Creating a fan performance measurement plan & selecting measurement planes
- Week 5 – Pressure considerations, Sizing ducts and estimating losses, Optimization techniques
- Week 6 – Psychrometrics and air density for fan systems, System effect in fan systems
- Week 7 – Fan system optimization strategies, Fan system evaluation with MEASUR
- Week 8 – Industrial Fan System VINPLT Wrap-up Presentations

Learning objectives session 3

Class participants will:

1. Apply simplified affinity laws to predict changed fan performance When density or rotational speed is changed.
2. Describe the characteristics of the 4 most common methods of controlling fan flow rate
   1. Speed control (VFD)
   2. Radial inlet vanes (VIV)
   3. Inlet box dampers (IBD)
   4. Outlet damper or system damper

Fan affinity Laws

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Generalized Affinity Laws

1st law

$$\left(\frac{Q_c}{Q}\right)=\left(\frac{D_c}{D}\right)^3\left(\frac{N_c}{N}\right)\left(\frac{K_p}{K_{Pc}}\right)$$

2nd law

$$\left(\frac{P_{tc}}{P_t}\right)=\left(\frac{D_c}{D}\right)^2\left(\frac{N_c}{N}\right)^2\left(\frac{K_p}{K_{Pc}}\right)\left(\frac{\rho_c}{\rho}\right)$$

3rd law

$$\left(\frac{P_{vc}}{P_v}\right)=\left(\frac{D_c}{D}\right)^2\left(\frac{N_c}{N}\right)^2\left(\frac{\rho_c}{\rho}\right)$$

Generalized Affinity Laws (cont.)

4th law

$$\left(\frac{H_c}{H}\right)=\left(\frac{D_c}{D}\right)^5\left(\frac{N_c}{N}\right)^3\left(\frac{K_p}{K_{Pc}}\right)\left(\frac{\rho_c}{\rho}\right)$$

5th law

$$P_{sc}=P_{tc}-P_{vc}$$

6th law

$$\eta_{sc}=\eta_{tc}\left(\frac{P_{sc}}{P_{tc}}\right)$$

Simplified Affinity Laws – density change

Changes in density when Kp can be neglected

$$\left(\frac{Q_c}{Q}\right) = \cancel{\left(\frac{D_c}{D}\right)^3} \cancel{\left(\frac{N_c}{N}\right)} \cancel{\left(\frac{K_p}{K_{Pc}}\right)}$$

$$\left(\frac{P_{tc}}{P_t}\right) = \cancel{\left(\frac{D_c}{D}\right)^2} \cancel{\left(\frac{N_c}{N}\right)^2} \cancel{\left(\frac{K_p}{K_{Pc}}\right)} \left(\frac{\rho_c}{\rho}\right)$$

$$\left(\frac{H_c}{H}\right) = \cancel{\left(\frac{D_c}{D}\right)^5} \cancel{\left(\frac{N_c}{N}\right)^3} \cancel{\left(\frac{K_p}{K_{Pc}}\right)} \left(\frac{\rho_c}{\rho}\right)$$

OR

$$Q_c = Q$$

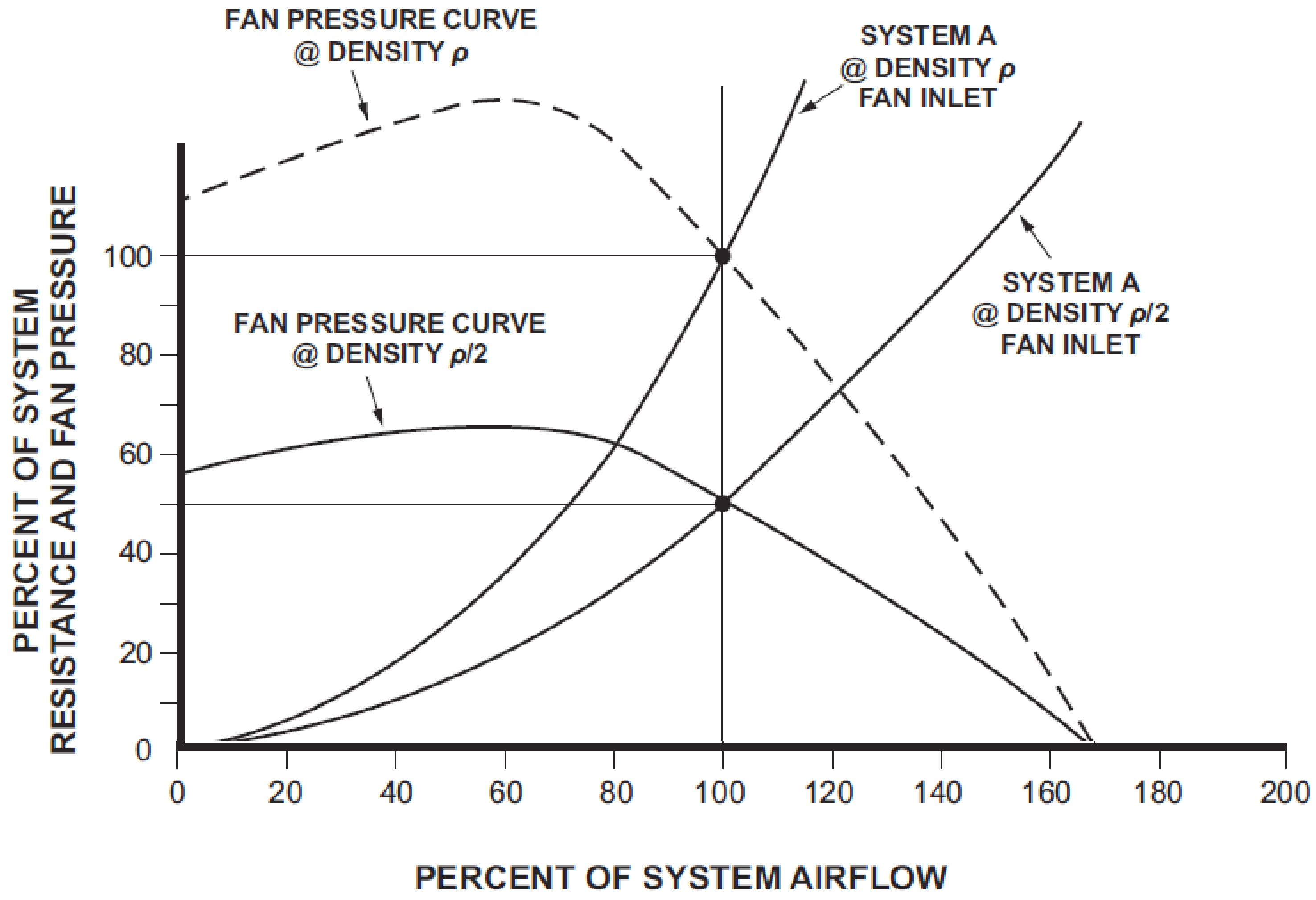
$$P_{tc} = P_t \times (\rho_c/\rho)$$

$$P_{sc} = P_s \times (\rho_c/\rho)$$

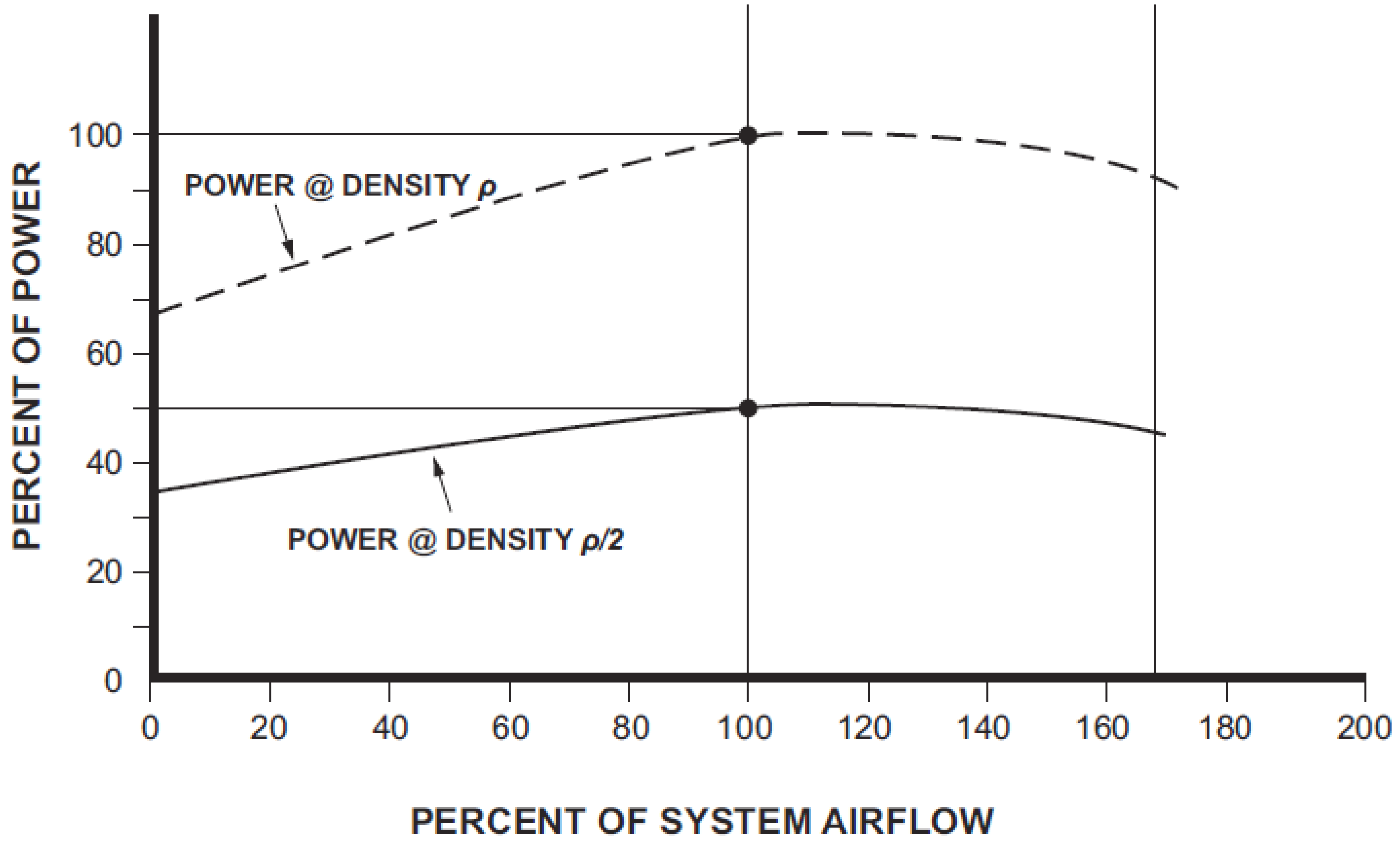
$$P_{vc} = P_v \times (\rho_c/\rho)$$

$$H_c = H \times (\rho_c/\rho)$$

Density change fan and system curves



Density change power curve



Simplified Affinity Laws – speed change

Changes in Fan speed when Kp can be neglected

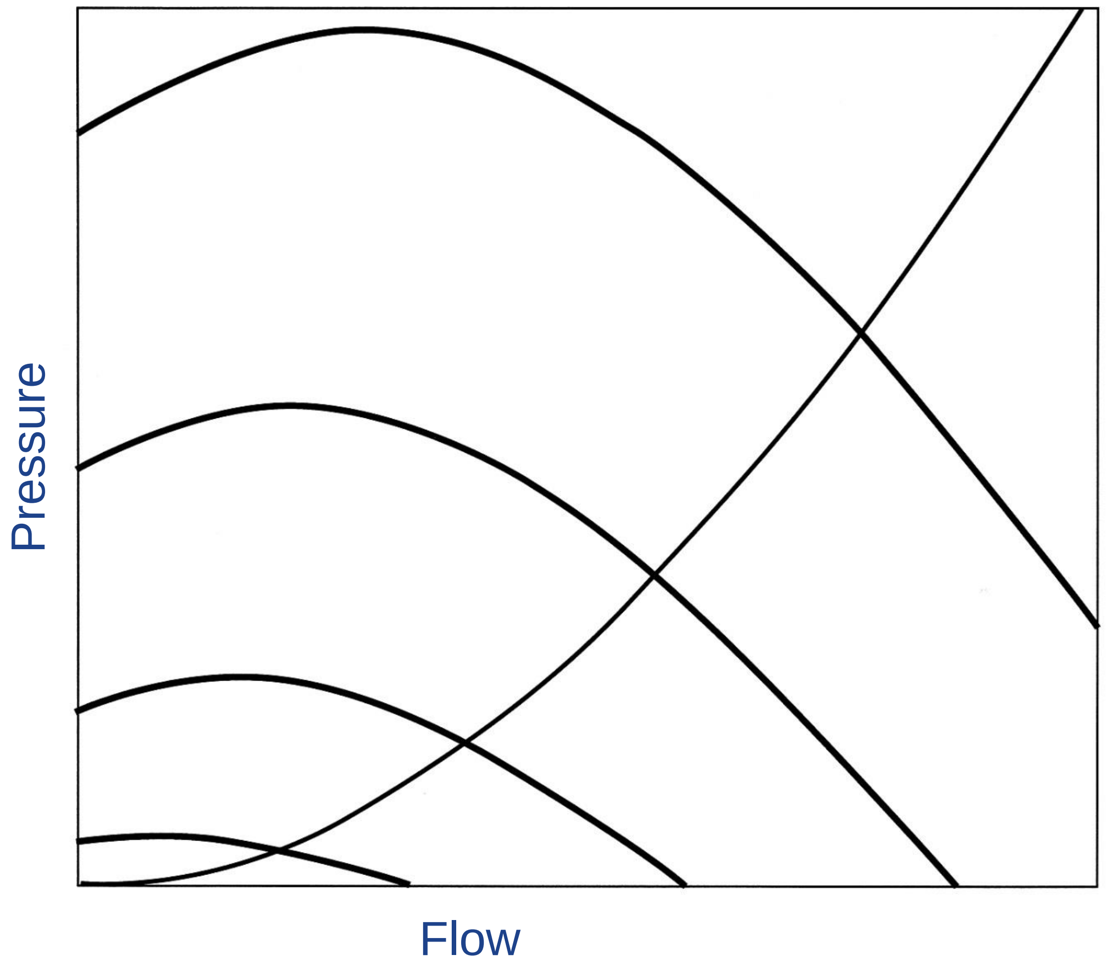
$$Q_c = Q \times \left(\frac{N_c}{N} \right)$$

$$P_c = P \times \left(\frac{N_c}{N} \right)^2$$

$$H_c = H \times \left(\frac{N_c}{N} \right)^3$$

$$H_c = \frac{P_c \times Q_c}{6356 \times \eta}$$

Fan Performance at Different Speeds



Changing Fan Speed overview

Technique	Advantages	Disadvantages
New Belt Drive Ratio	• Inexpensive • Quick fix	• Damper control required
Convert to Belt Drive	• Mechanical modification only	• Can be expensive • Damper control
Variable Speed Drive	• Optimal efficiency • Excellent process control	• Can be expensive • Press reduced with speed
Fluid Couplings	• Speed control for efficiency turndown and process control	• Inefficient at high turndown • Mechanical issues • Oil, Cooling water

Polling Question 1 -3
Fan Law – Rotational Speed Change

Polling Question

A fan's original operation at 1200 rpm was:

Flow	50,000 cfm
Pressure	12 in.w.g.
Power	128,700 W

The fan speed is then slowed to 840 rpm. Apply the simplified affinity laws to calculate the new flow, pressure and power.

	A	B	C	D	E
Q1 Flow	25000	35000	24500	17150	12500
Q2 Pressure	6.00	8.40	5.88	4.12	3.00
Q3 Power	64350	90090	63063	44144.1	32175

Fan system Control

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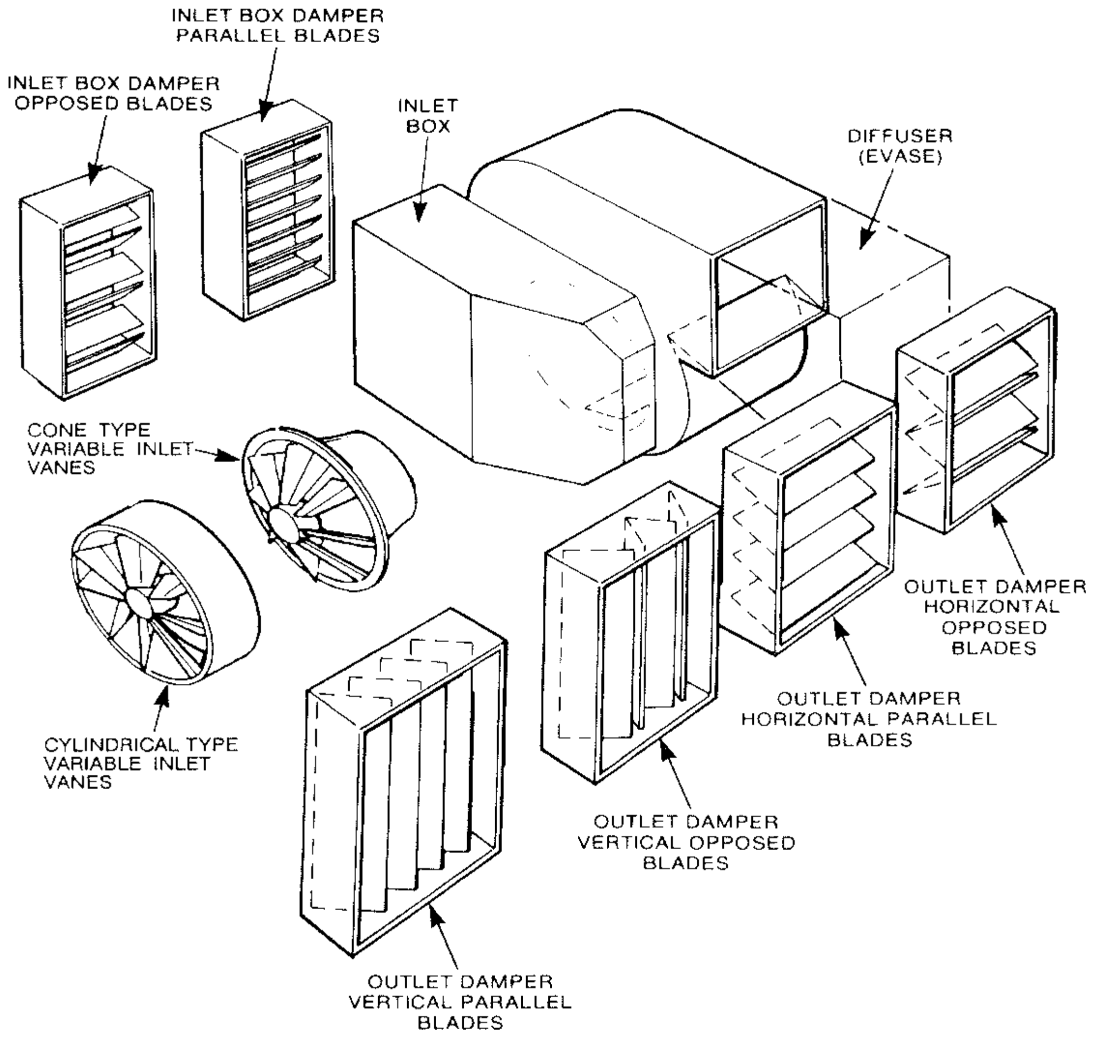
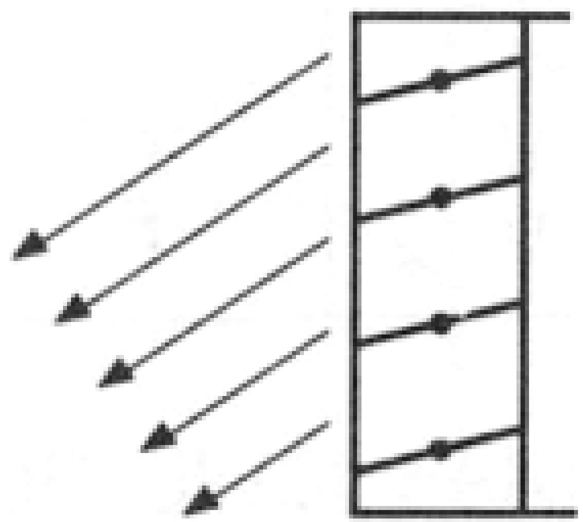
Fan Accessories and Dampers

- Caveat Emptor!
- Avoid Inlet Dampers
- Use VFD with Caution
- Avoid Discharge Dampers

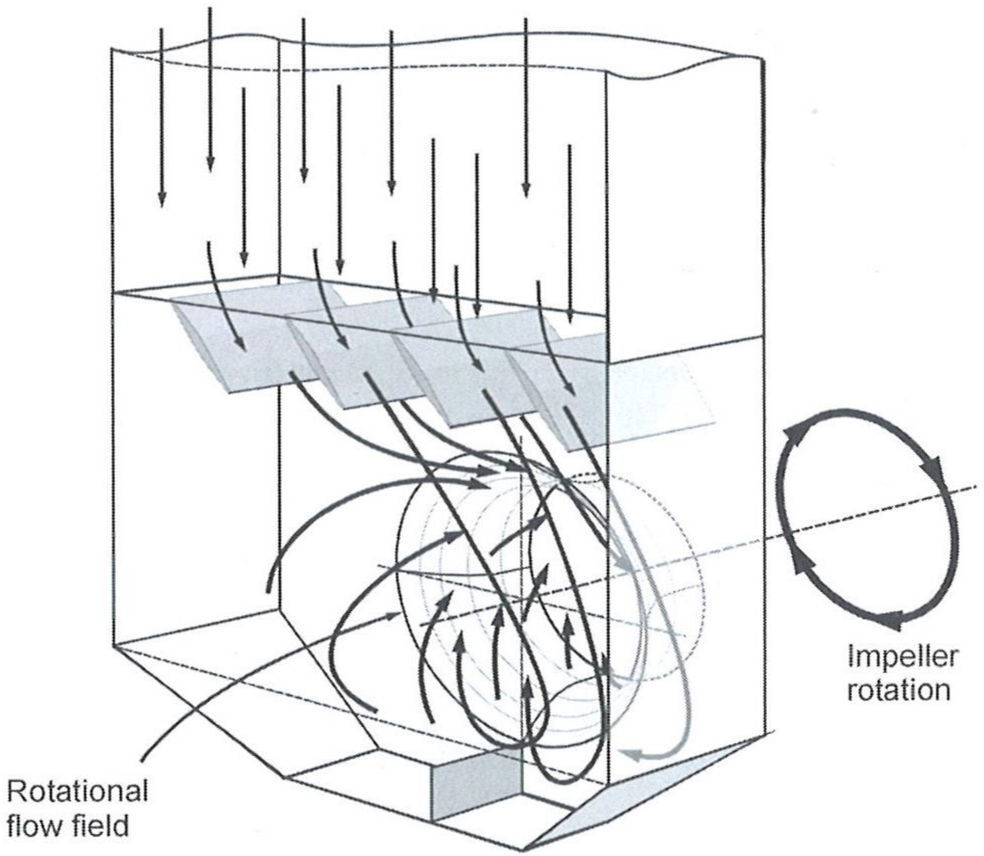


Parallel Blade Damper

- Used in conjunction with an inlet box, the parallel blade damper can reduce power usage somewhat
- When used elsewhere in the fan system:
  - Can create inefficient, non-uniform airflow
  - Best used as a shut off damper

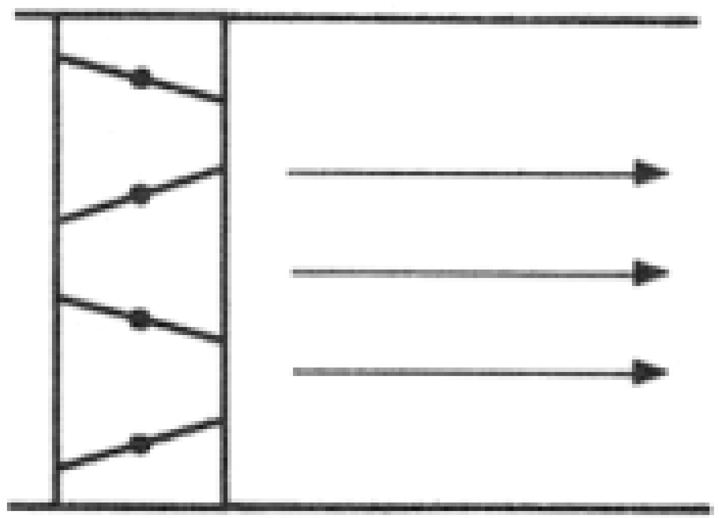


Swirl Flow in Inlet Box with ILD Partly Closed



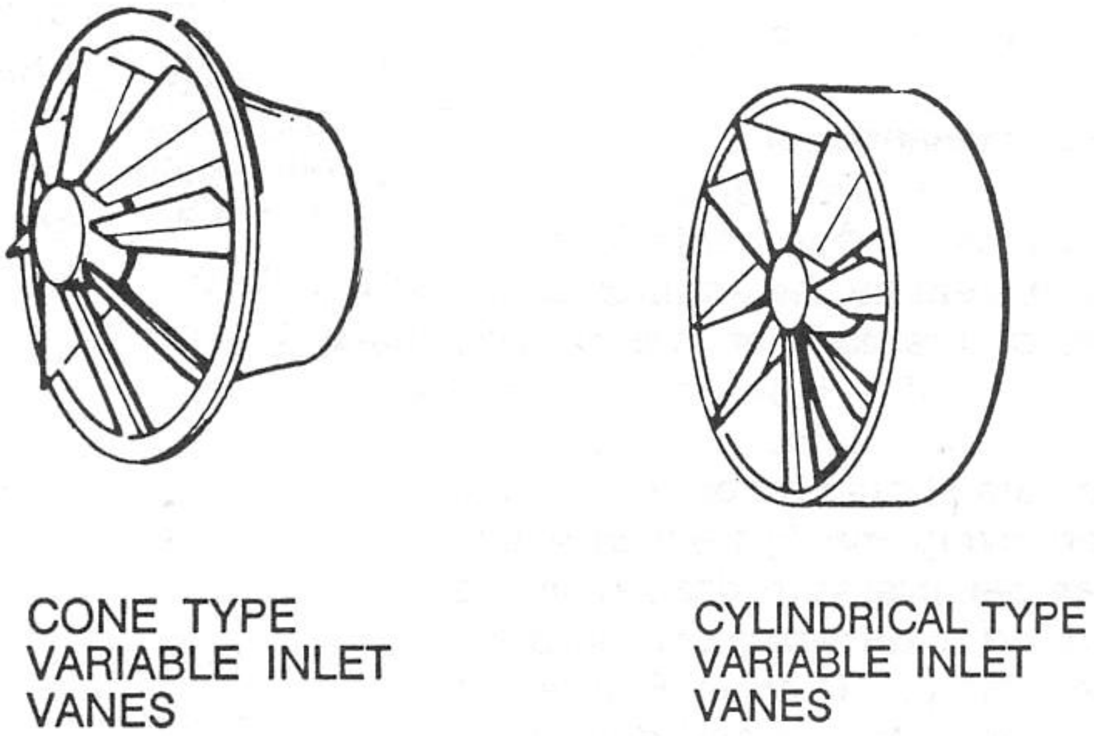
Opposed Blade Damper

- This type of damper can sometimes be found at the fan outlet, (outlet damper)
- Also found elsewhere in the fan system, (system damper)
- Each blade rotates in opposite direction
- Produces uniform airflow
- More stable control



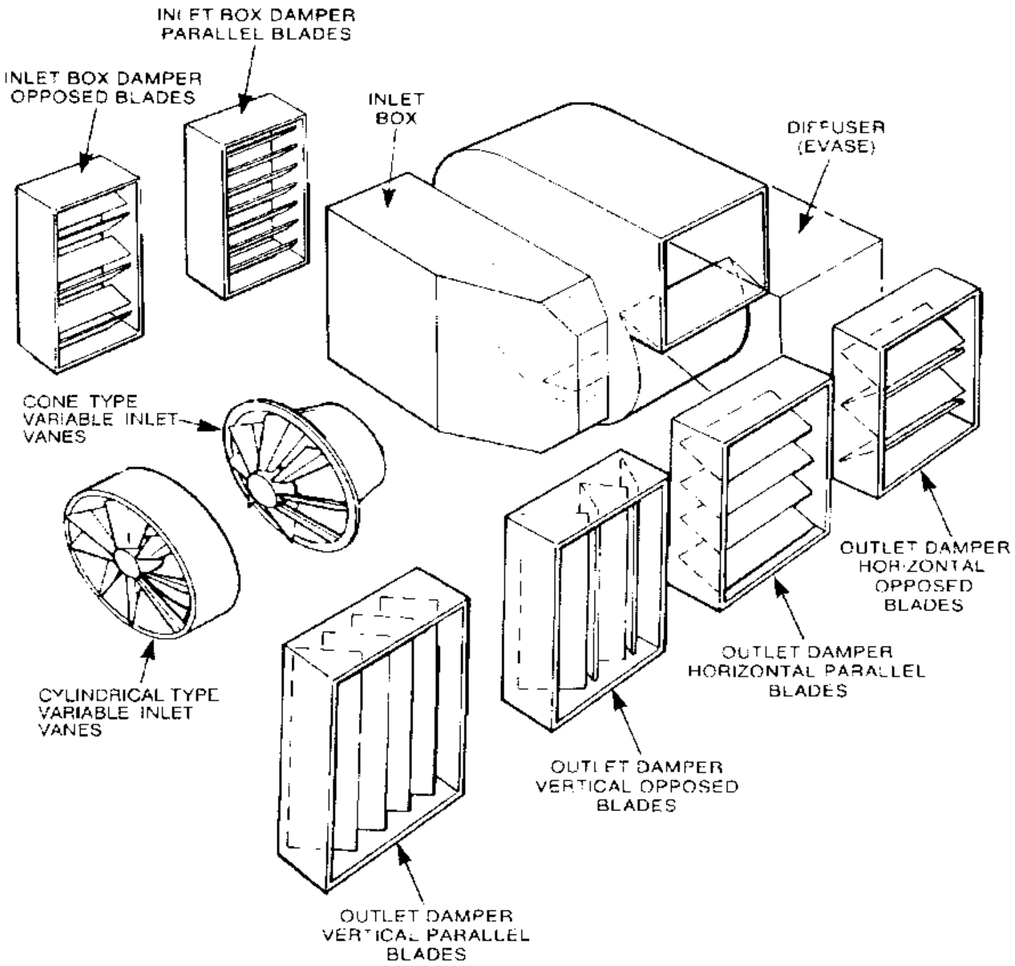
Variable Inlet Vanes

- Pie-shaped blades
- Slightly more efficient
- Use to trim airflow down to 85%



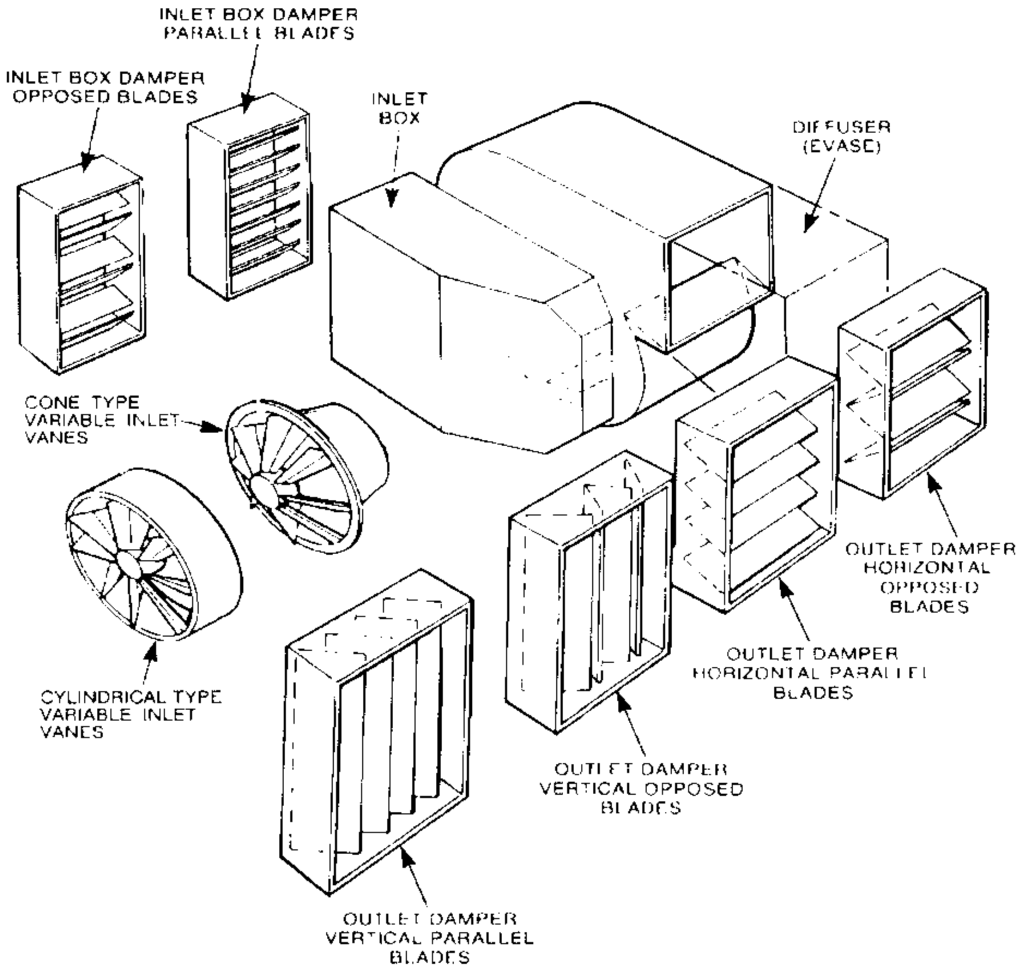
Inlet Louver Damper

- Located at fan inlet
- Parallel bladed
- Used with an inlet box

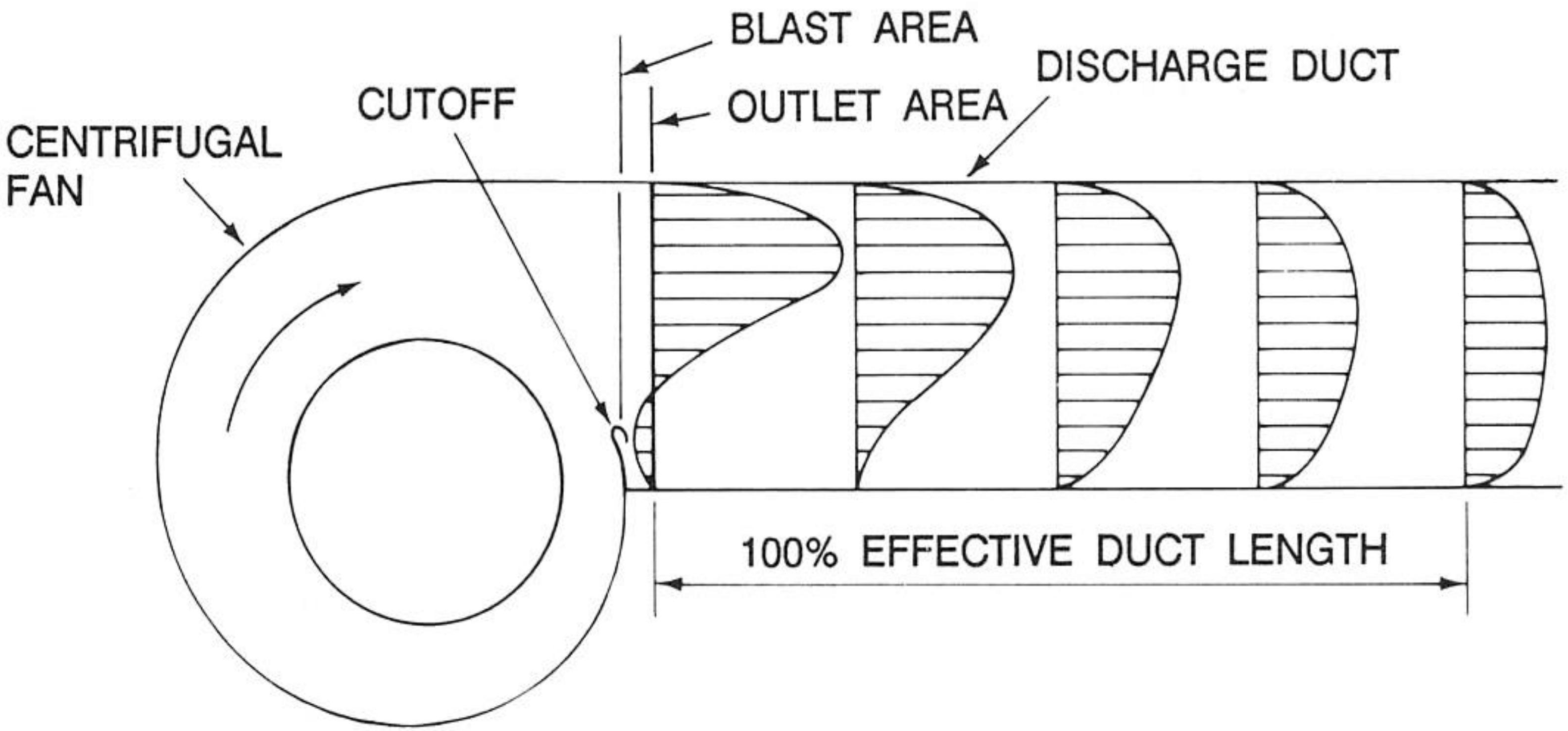


Outlet Louver Damper

- Bolted to the fan outlet
- Worst place for a damper

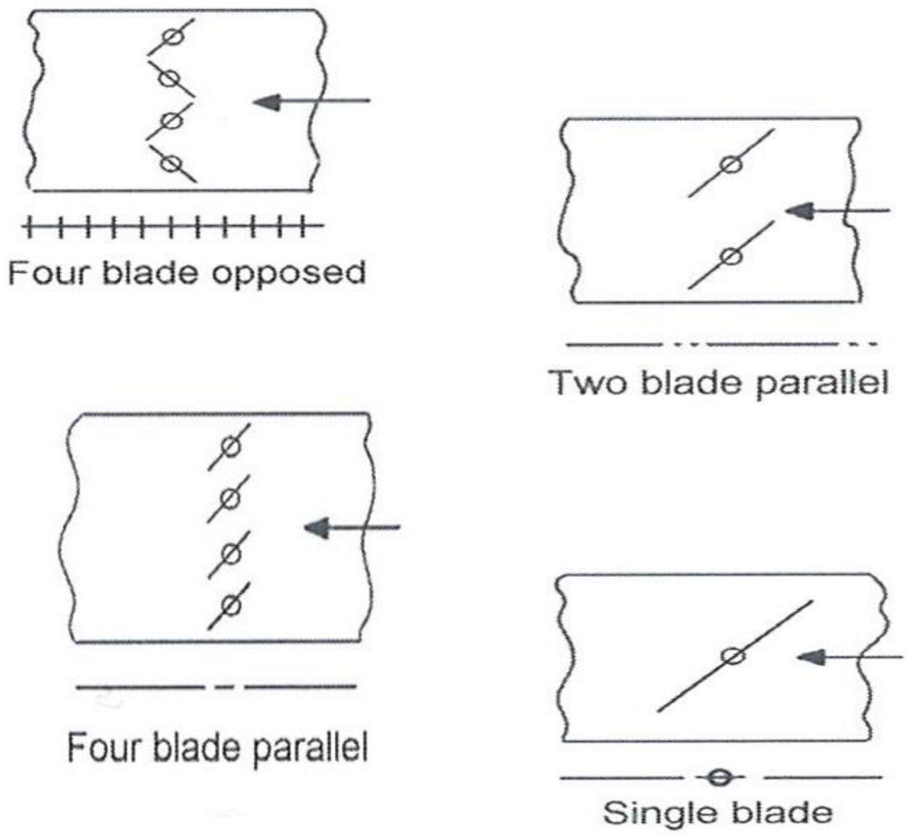


Fan Outlet Velocity Distribution

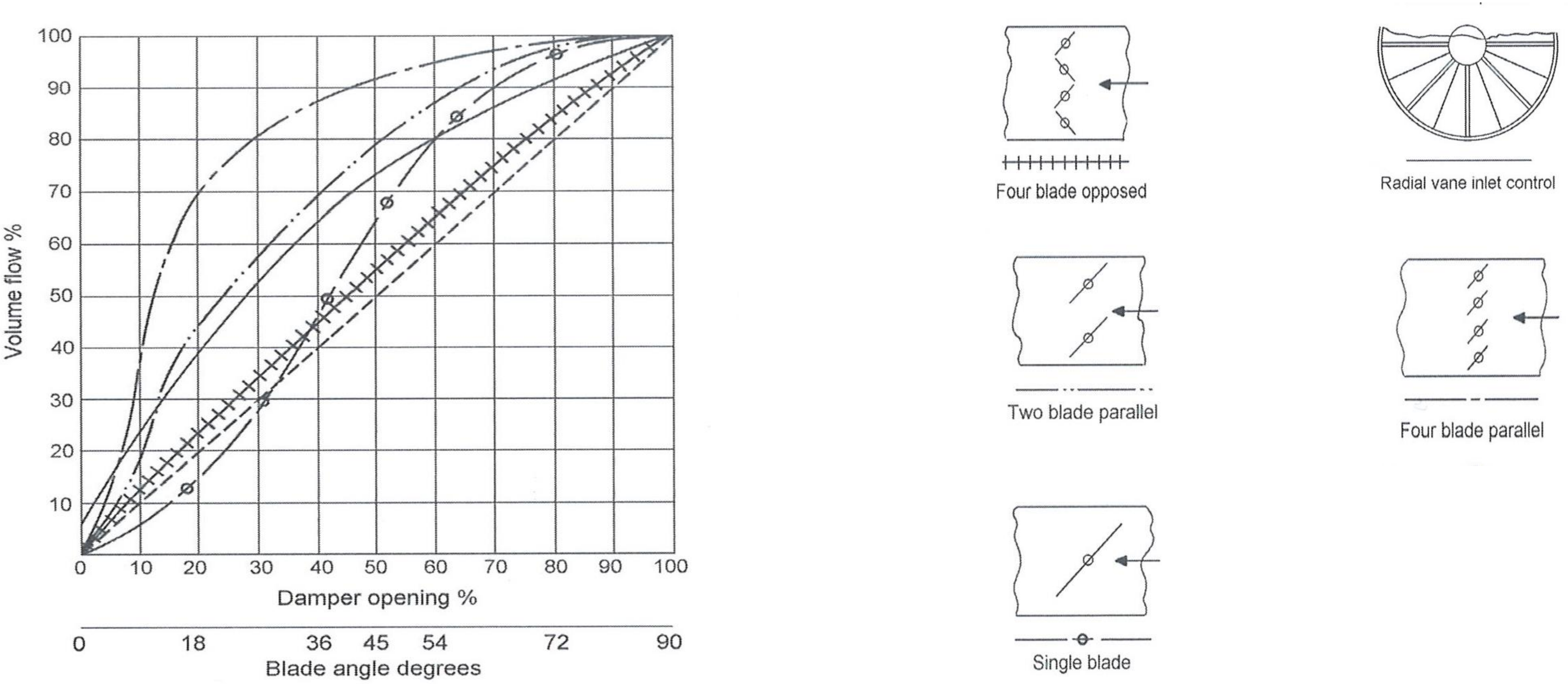


System Damper

- Located elsewhere in the ductwork
- Types
  - Opposed blade
  - Parallel blade
  - Butterfly
  - Single leaf



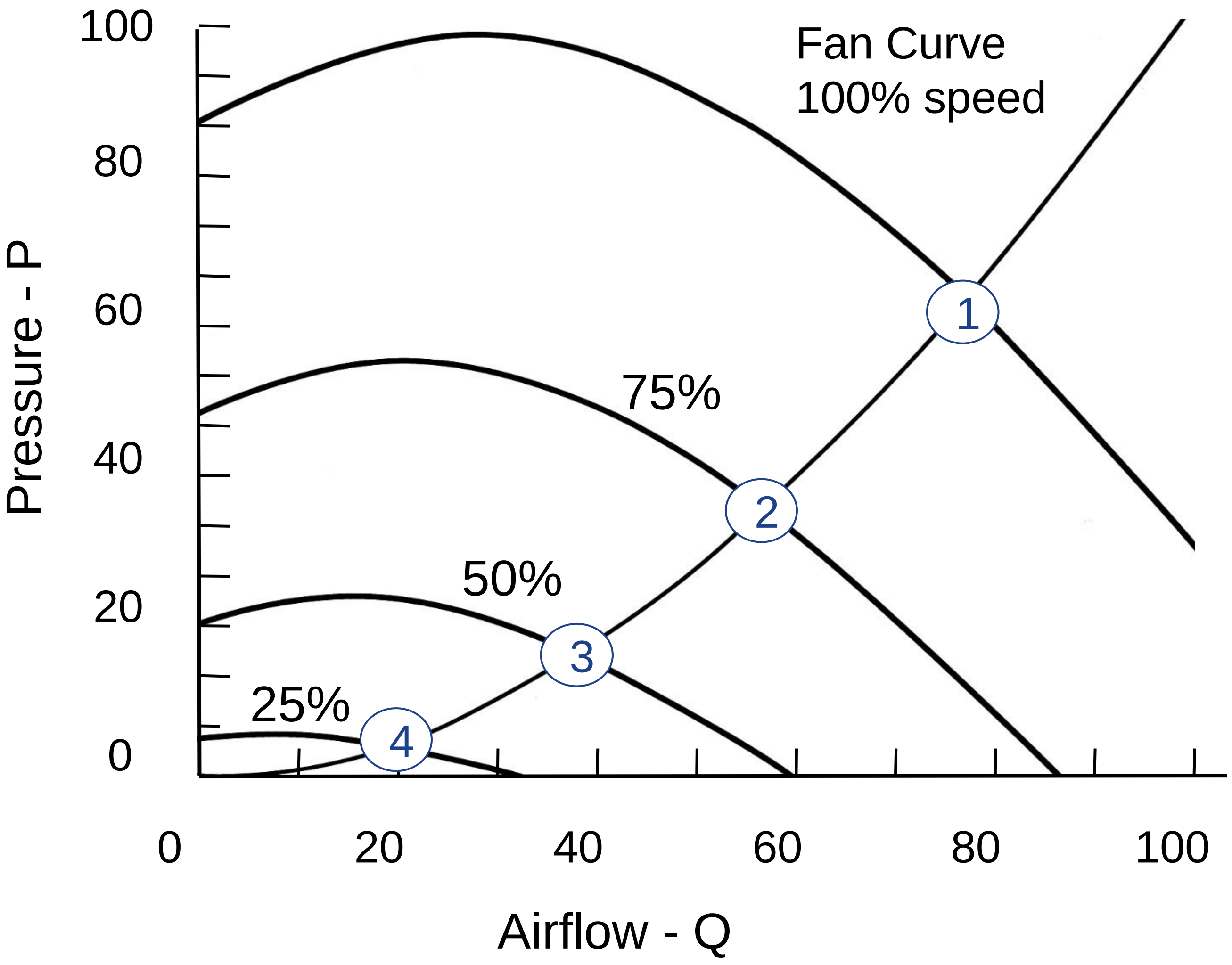
Damper Response



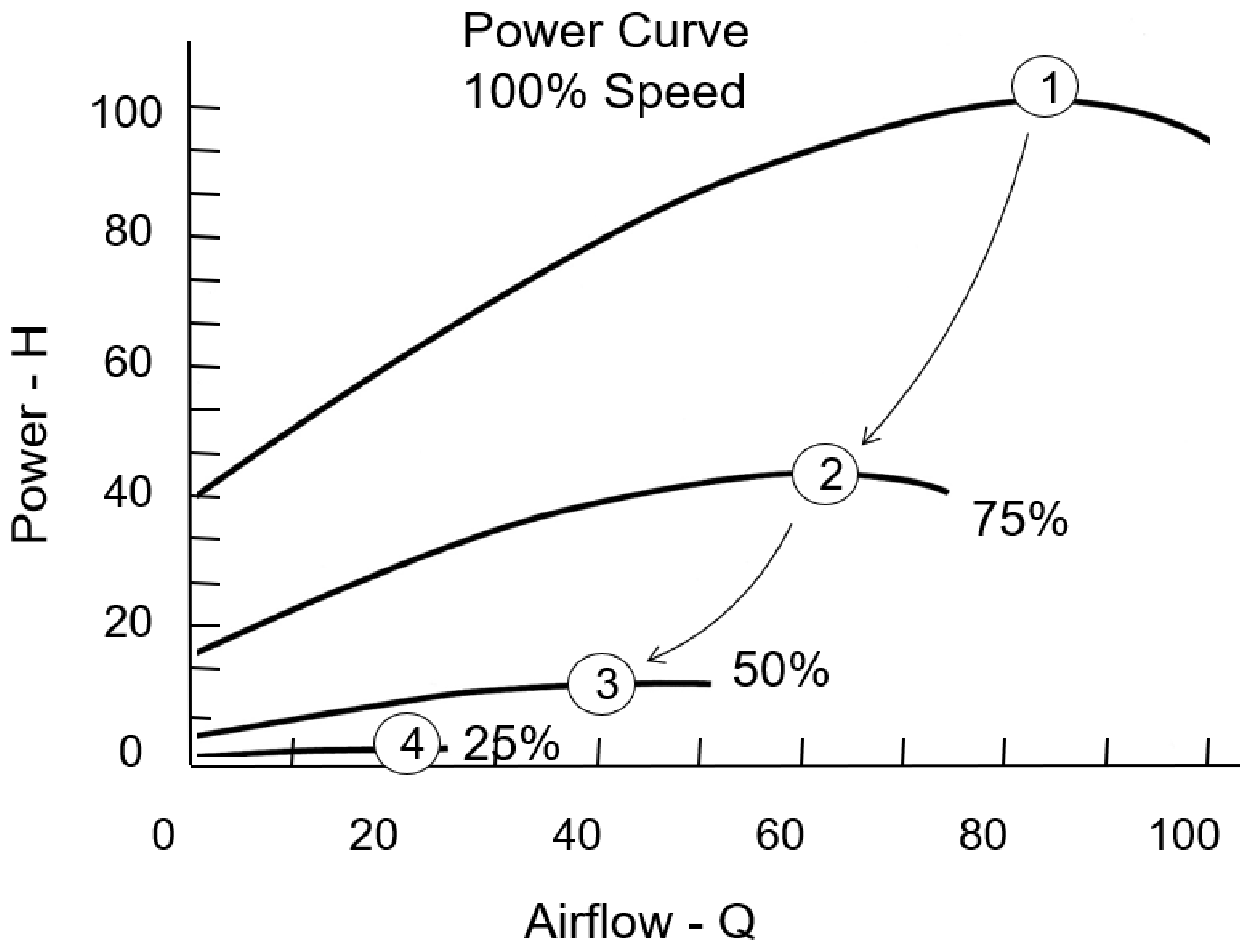
Variable Frequency Drive

- Constantly adjusts the motor speed (and therefore fan capacity) to meet changing process needs
- Cost has been dropping
- Reliability has improved

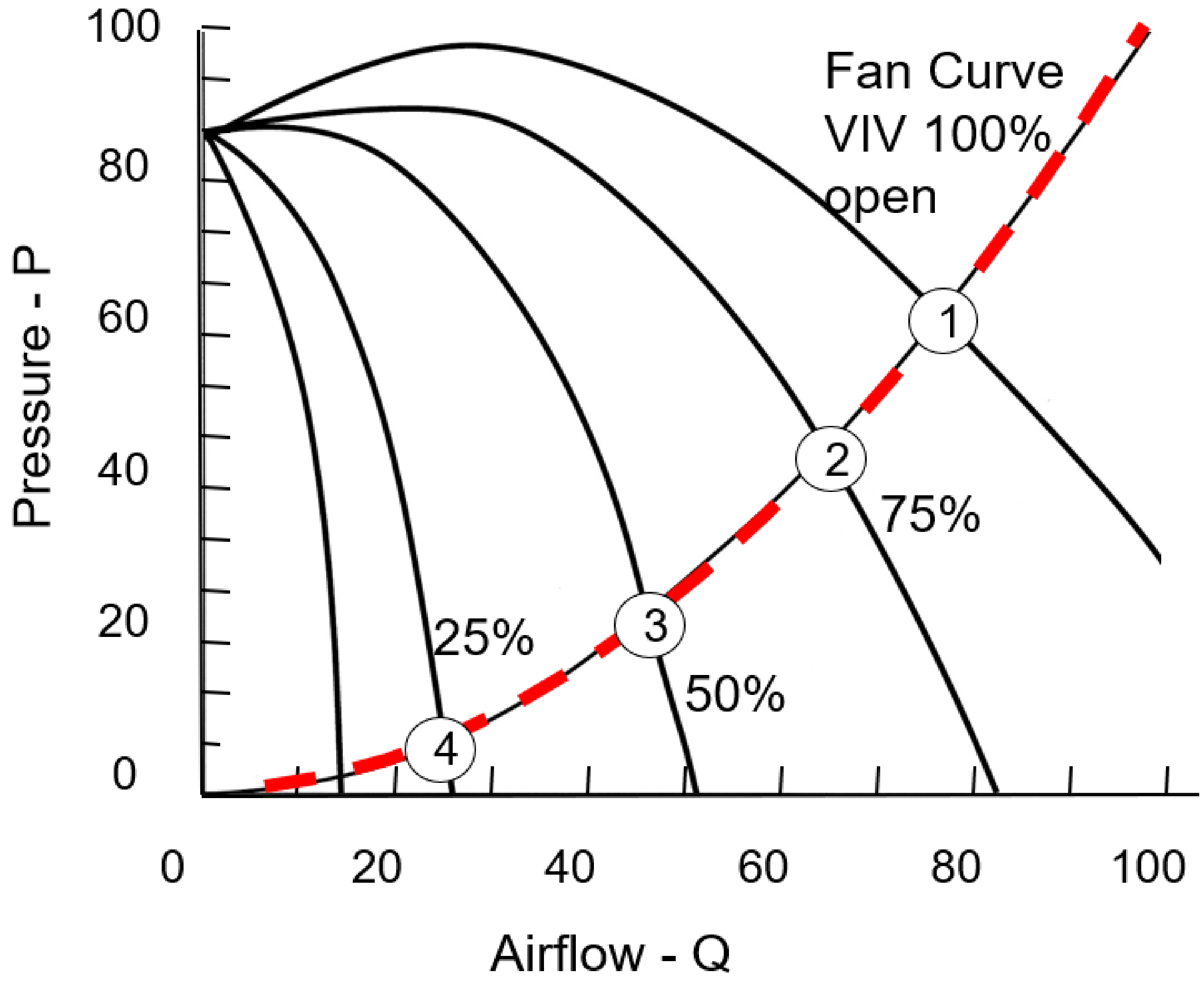
Fan Performance Curve with Variable Speed Drive



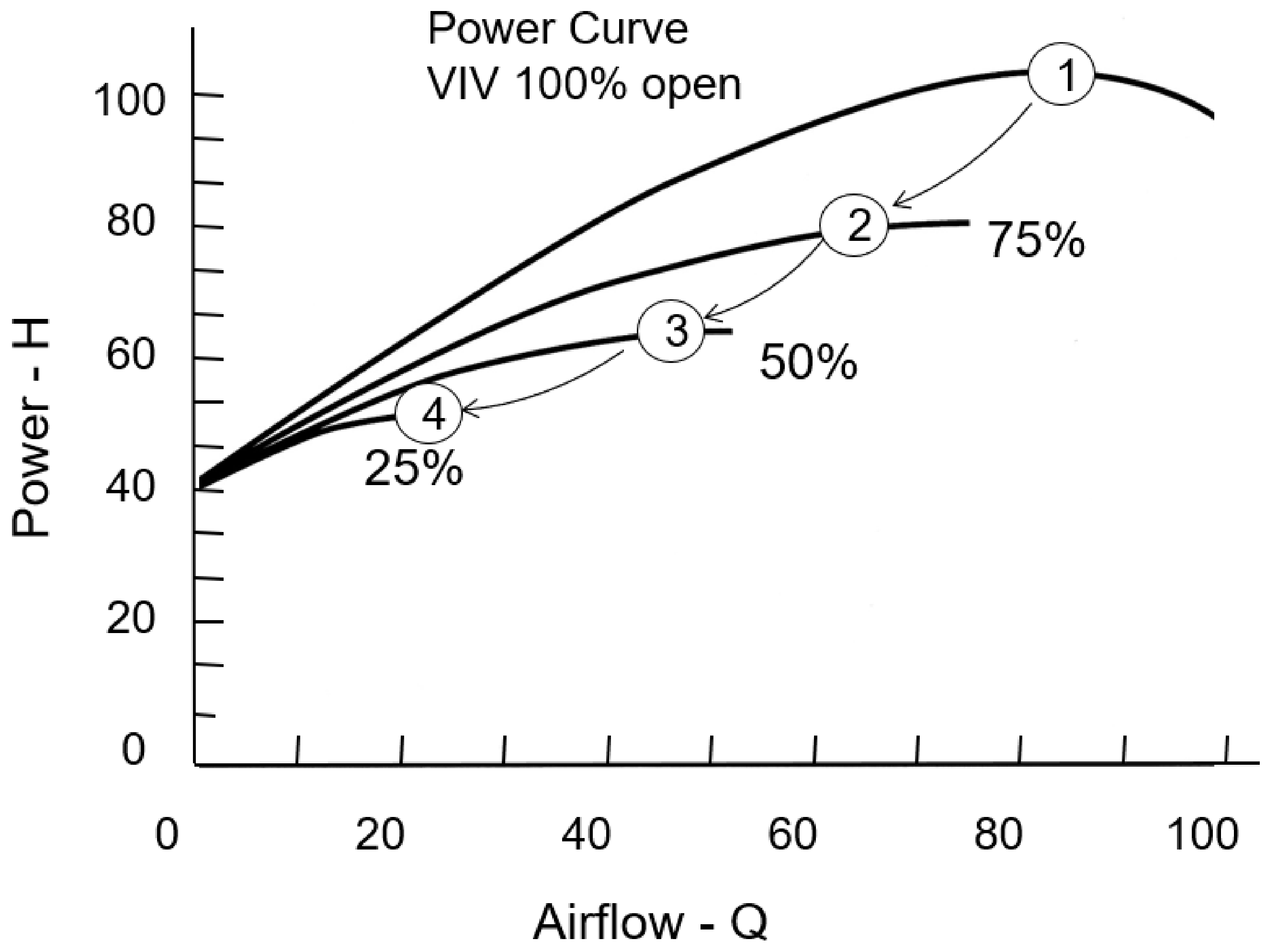
Fan Power Curve with Variable Speed Drive



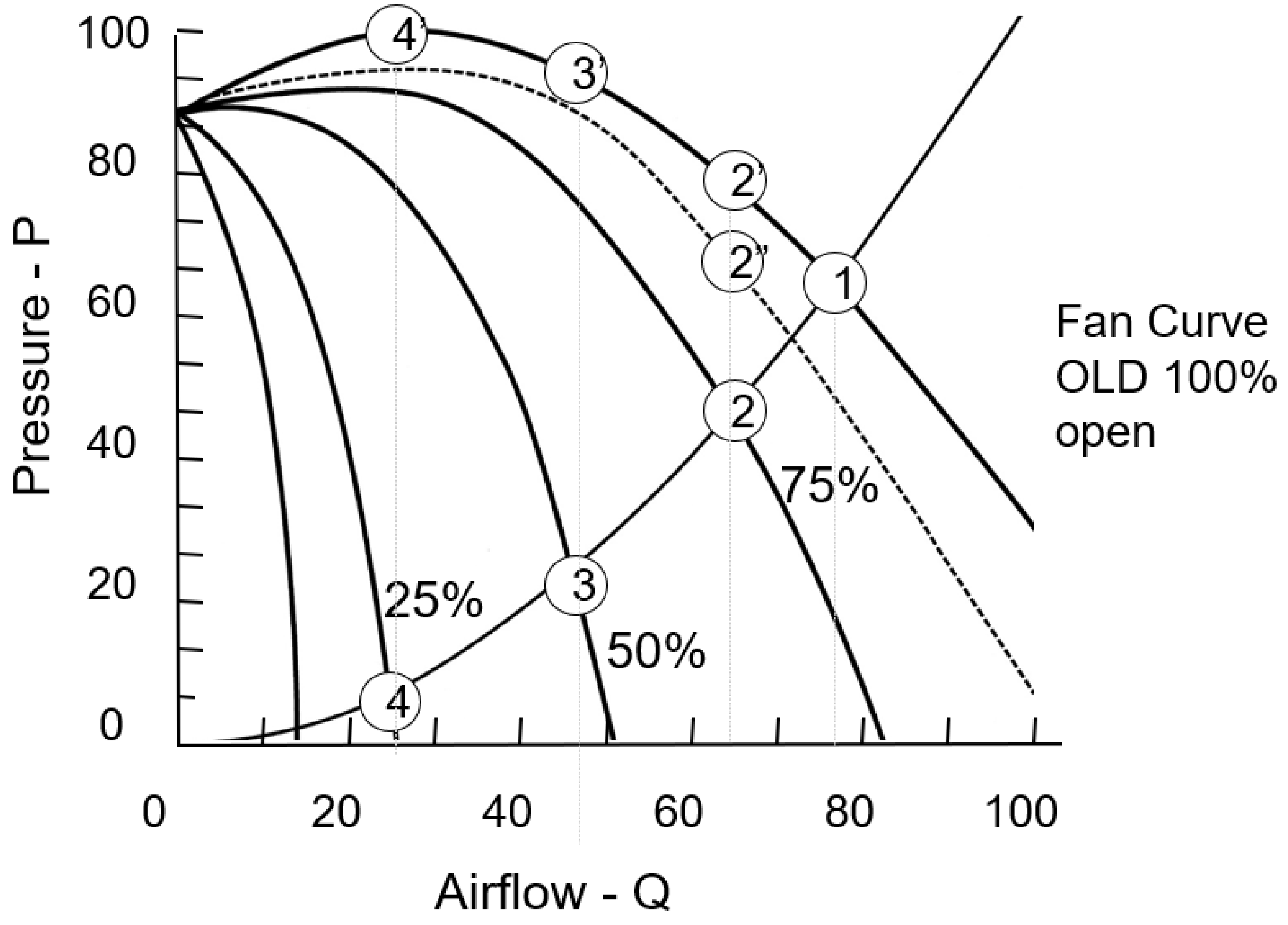
Fan Performance Curve with Variable Inlet Vanes



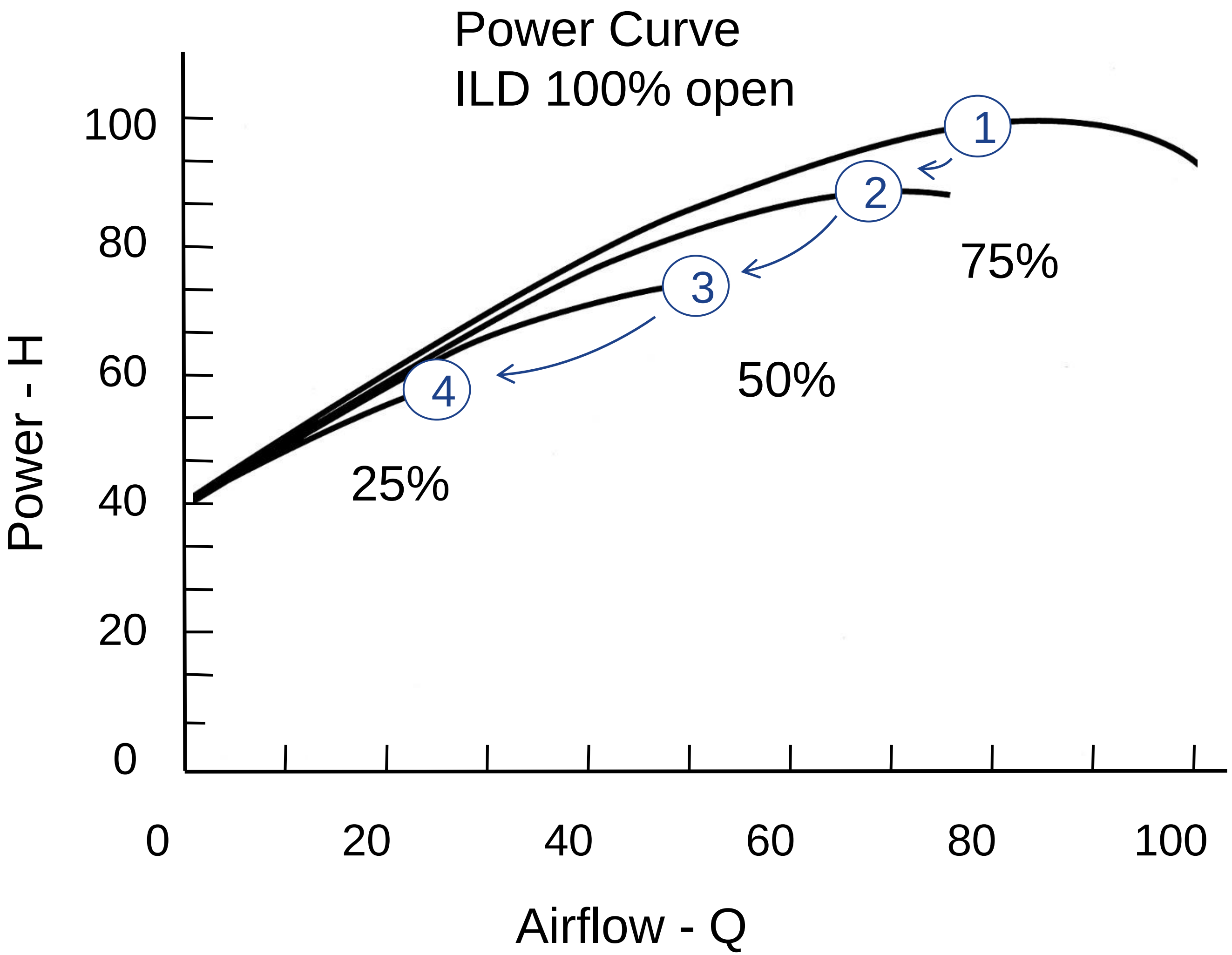
Varying Power Curves for Variable Inlet Vanes



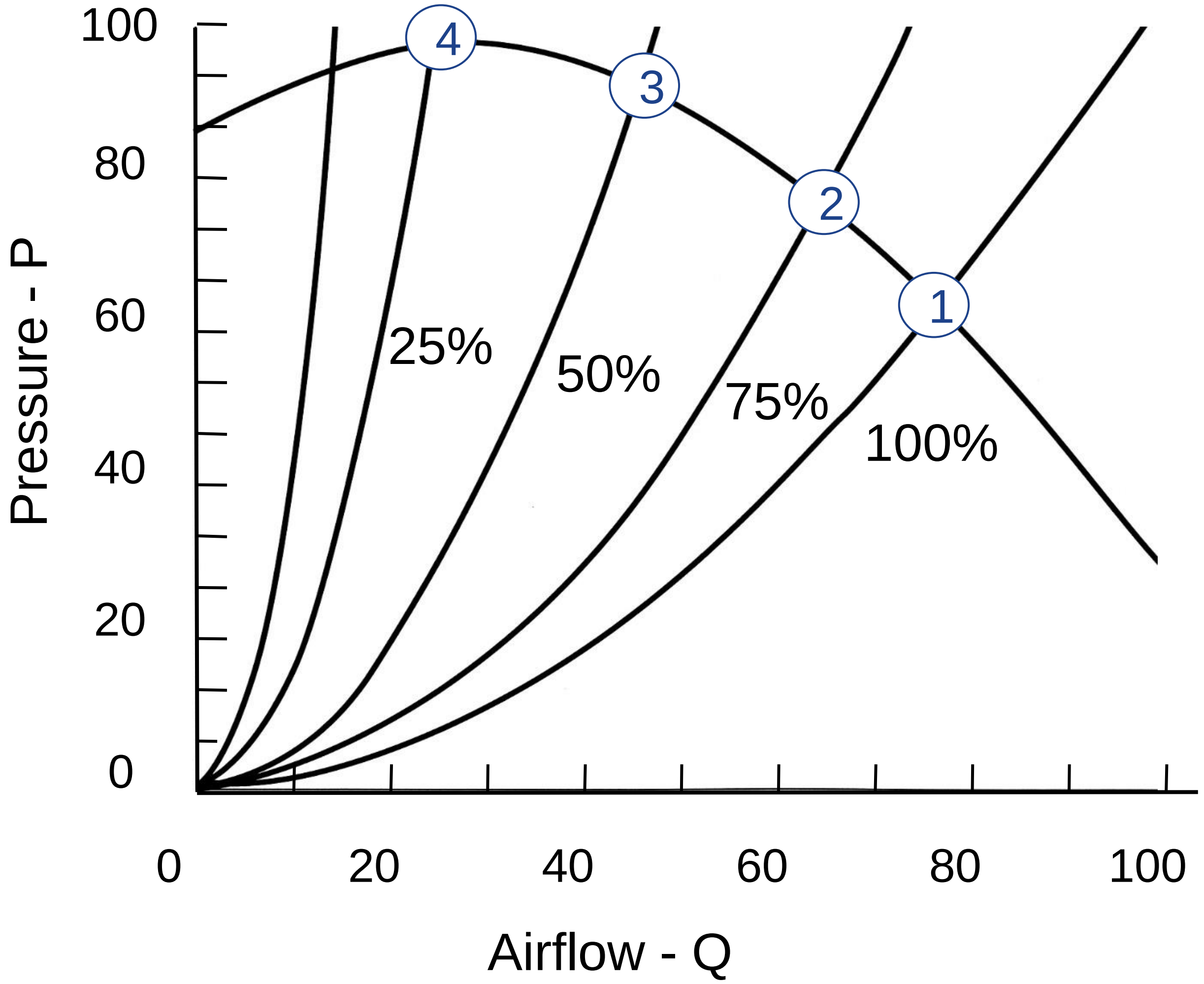
Fan Performance Curve for Inlet Louver Damper



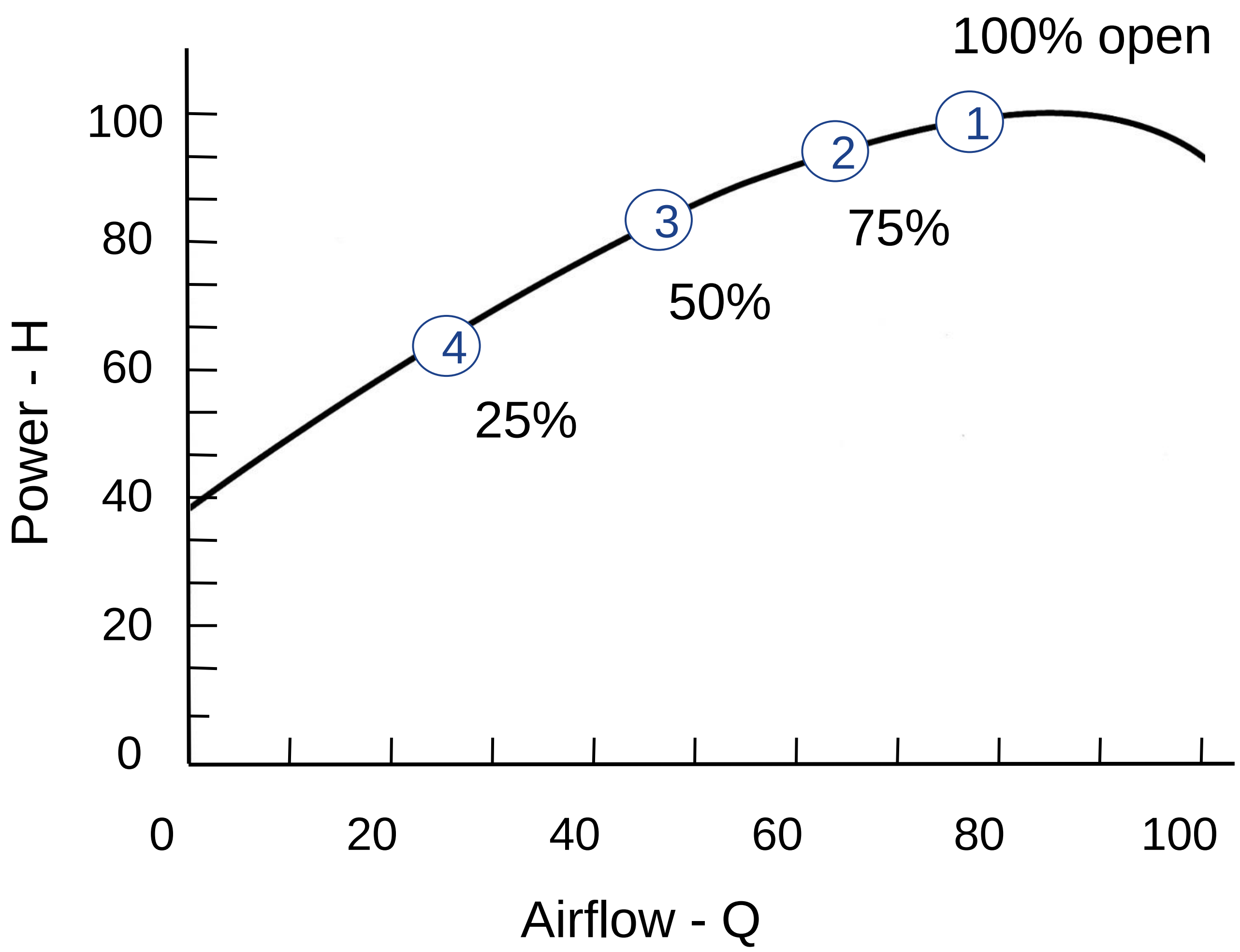
Fan Power Curves for Inlet Louver Damper



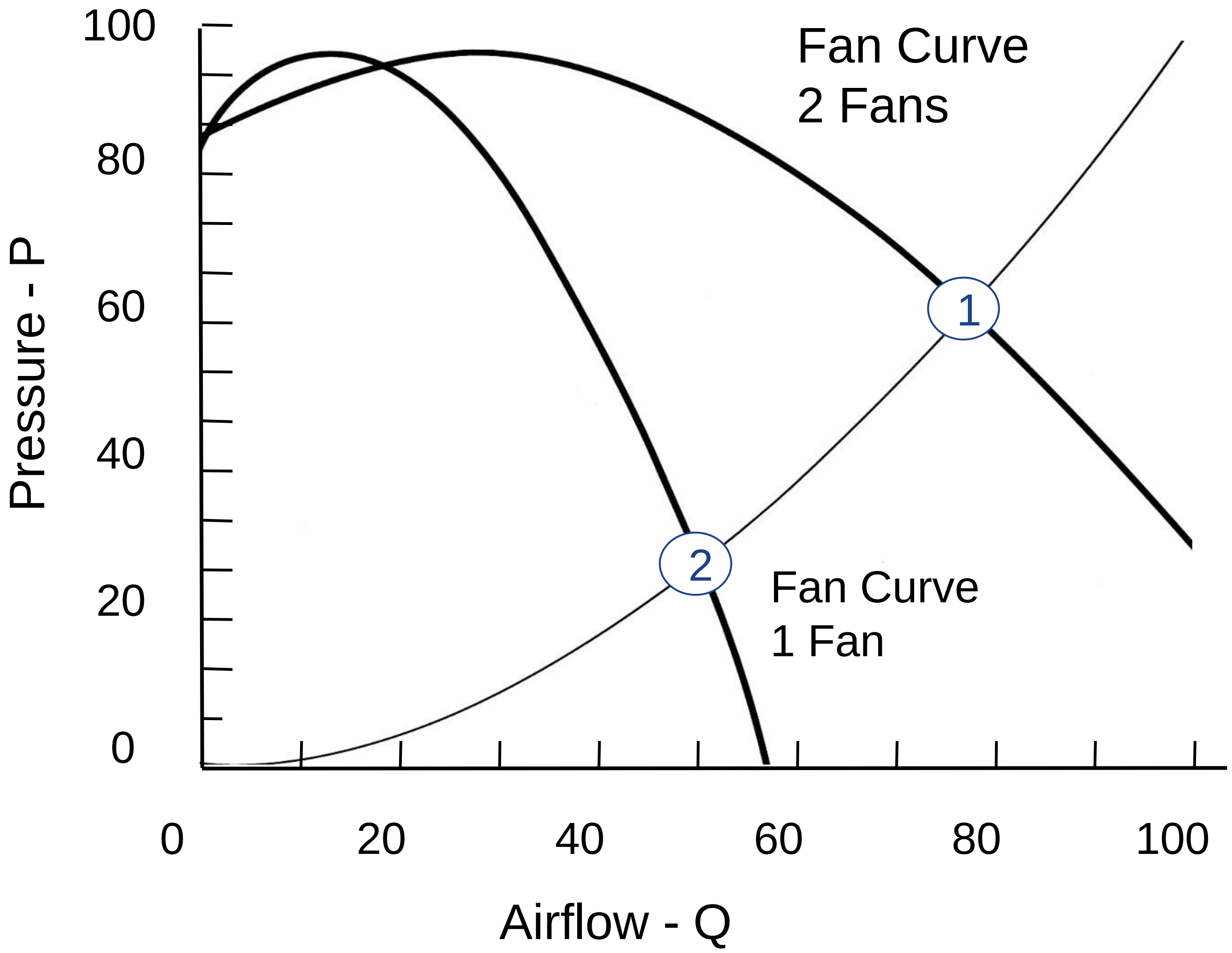
Fan Curve for Outlet Louver Damper



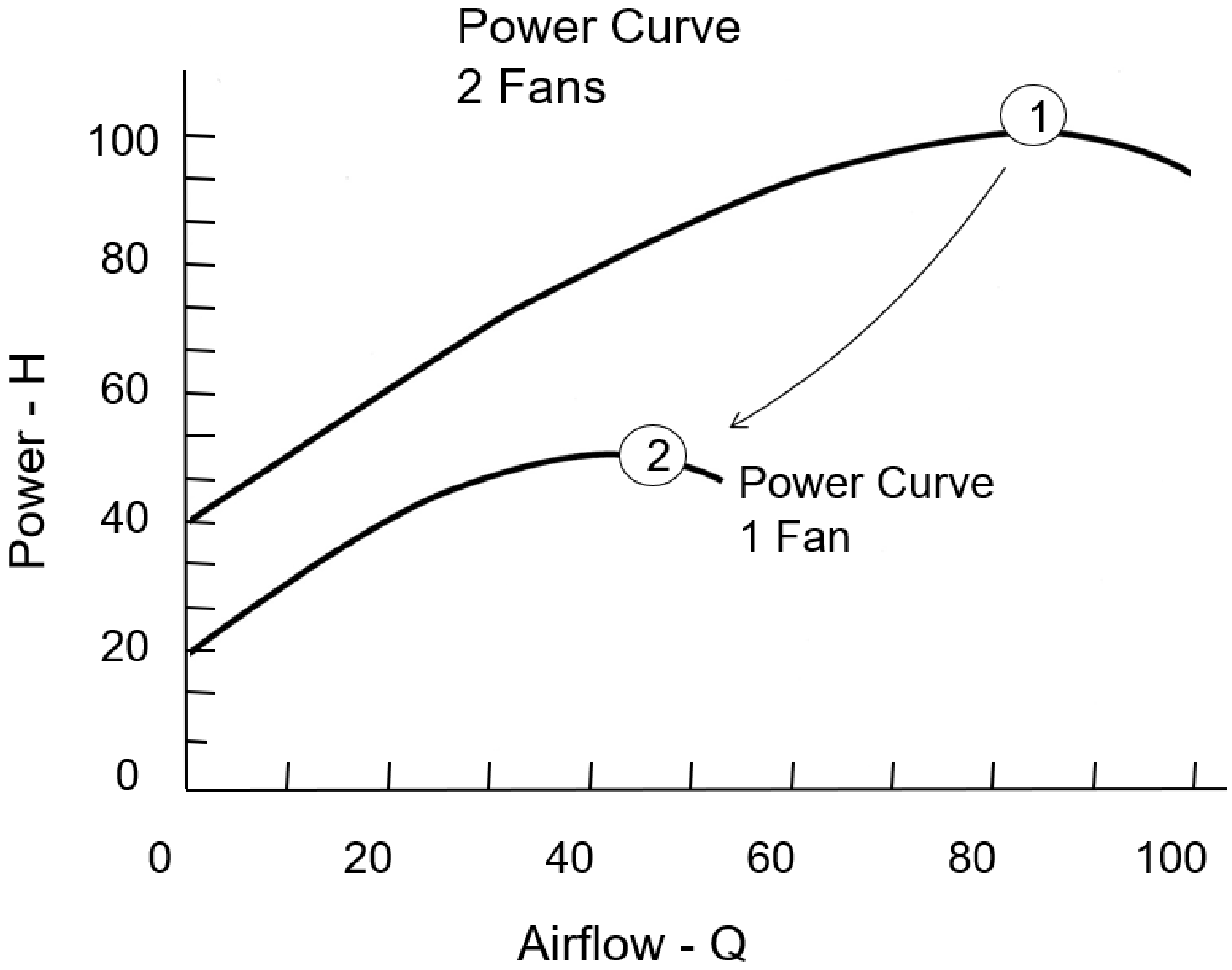
Fan Power Curve for Outlet Louver Damper



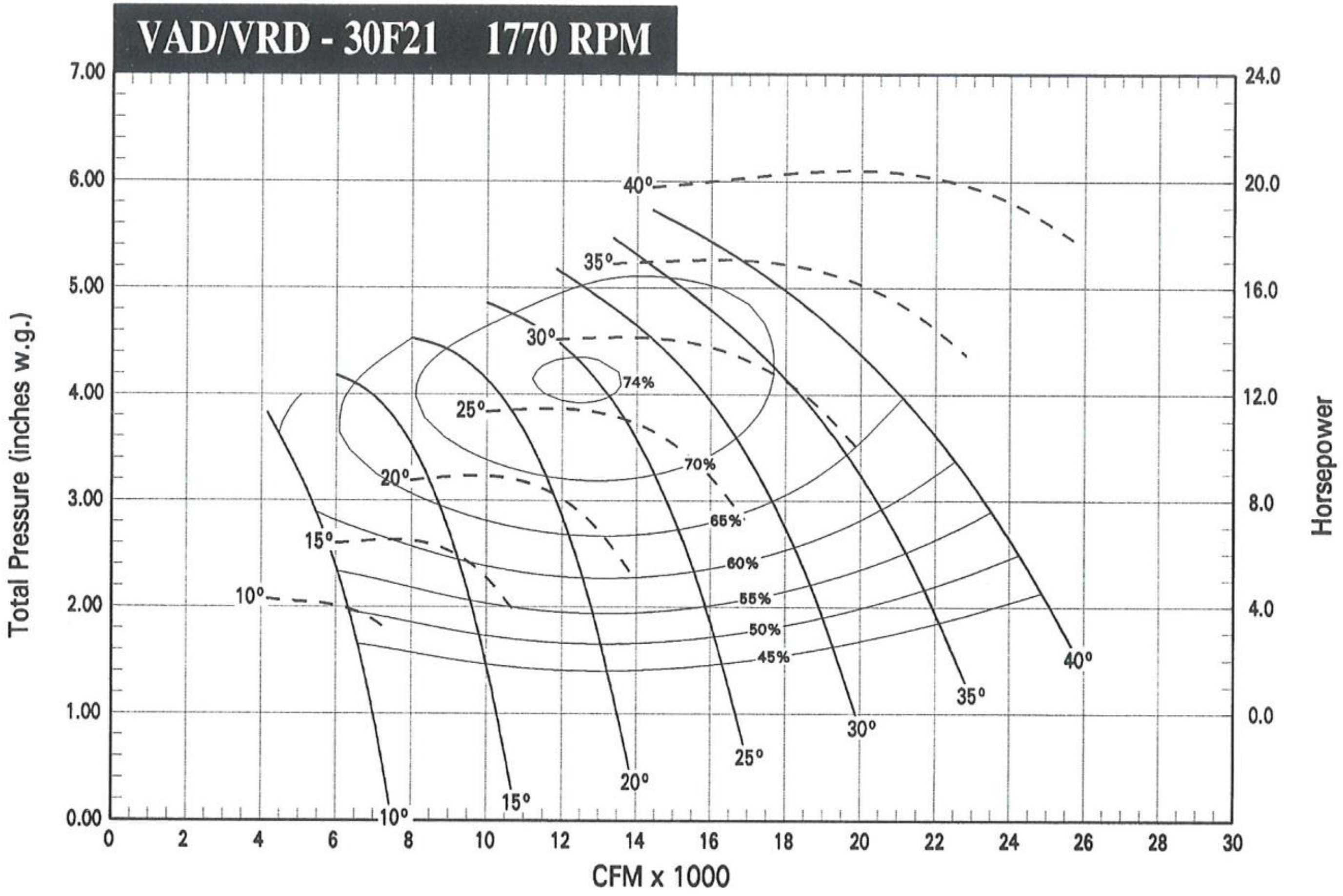
Fan Performance Curve for Two Fans in Parallel



Fan Power Curve for Two Parallel Fans

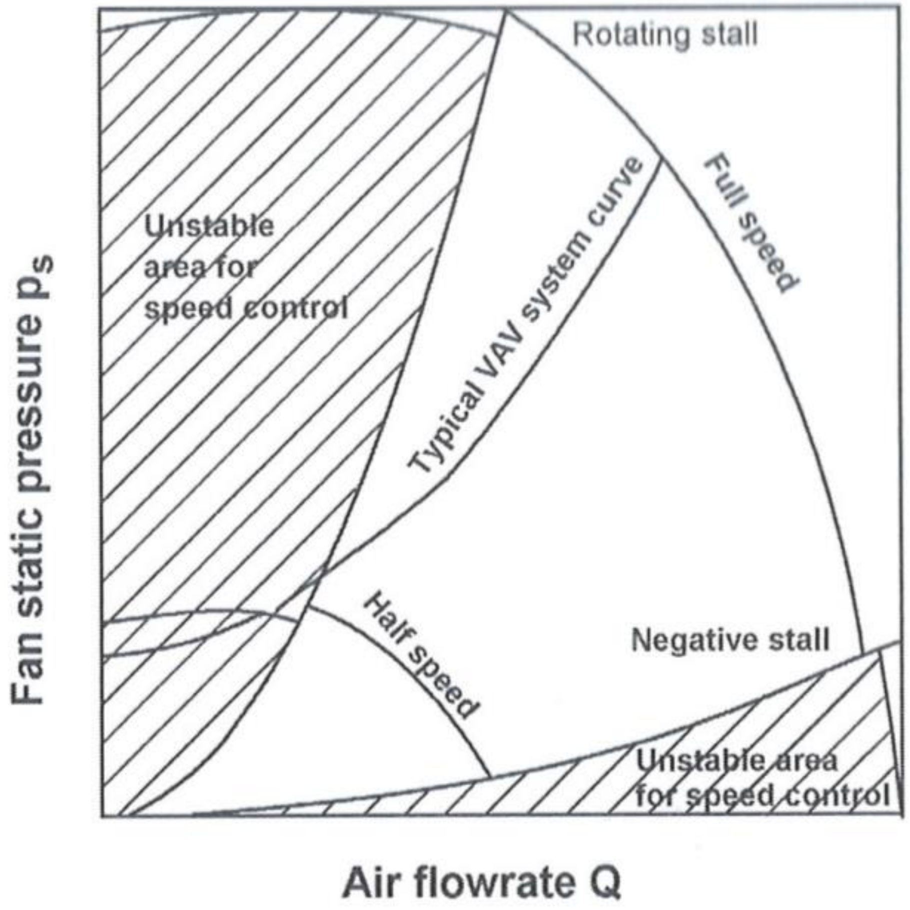


Variable Pitch Axial Fan Characteristic

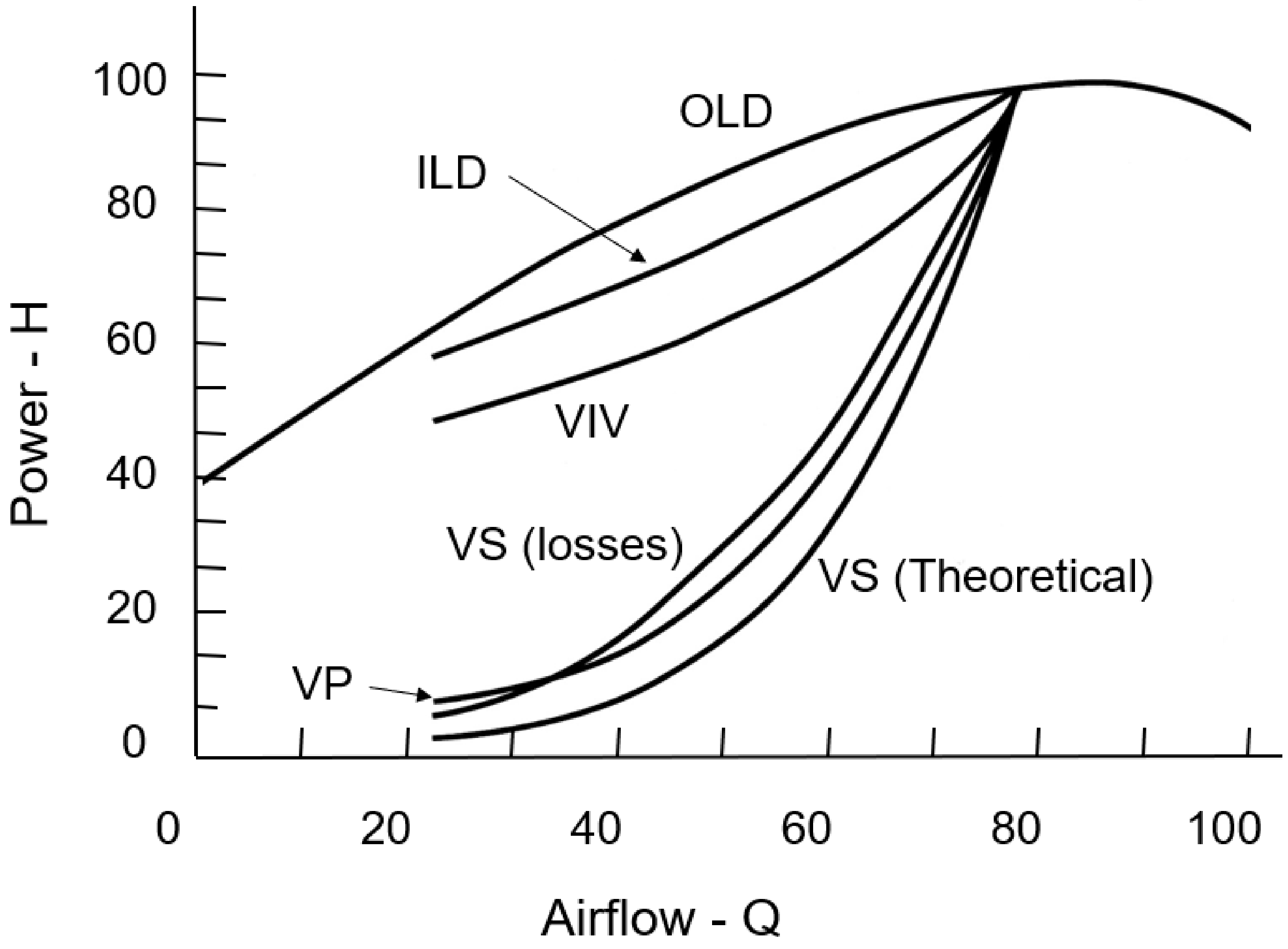


Performance shown is for Model VAD/VRD with inlet and outlet ducts.

VAV System Characteristic Curve and Fan Stall Regions for Backward Bladed Fans



Comparison of Fan Control Methods



Polling Question 4-6

Polling Question

4) Among the following control methods which is generally the least efficient?

a) Variable Frequency Drive b) Variable Inlet vanes c) Inlet box damper d) Outlet damper

5) Among the following control types which is generally the most efficient?

a) Variable Frequency Drive b) Variable Inlet vanes c) Inlet box damper d) Outlet damper

6) Among the following control types which is generally the most efficient?

a) Variable Inlet vanes b) Inlet box damper c) Outlet damper d) System Damper

Key Points / Action Items

1. When changing the rotational speed of a fan:
   - The change in flow is directly proportional to the speed change
   - The change in pressure is proportional to the square of the speed change,
   - The change in power is proportional to the cube of the speed change

2. Normally slowing down the fan is more efficient than using a damper to control the flow

3. Variable Inlet Vanes are generally the most efficient form of damper control, since they impart a pre-swirl

4. Avoid using a VFD for constant flow application.

5. Especially avoid using a VFD for applications with high constant pressure requirements

Homework #3

- Identify the type of fan control used on the top 10 fans in your facility
- Are there any systems with damper control where the damper is less than 90% open?

Thank You all for attending today’s webinar.

See you all on next Thursday –

If you have specific questions, please stay online and we will try and answer them.

Alternately, you can email questions to me at ron@productiveenergy.com

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