2012 Spring AIHA PDC

Ductwork Issues
Objectives

- Become familiar with air flow and energy consumption/design issues in duct issues:
  - Blast gates vs. balancing by design
  - Resistance to flow in ducts
  - Balancing at a junction
  - Air stream acceleration & deceleration
    - At a junction
    - Duct expansions & contractions
Balancing Methods

- With blast gates
- By design
Blast Gate Method

- **Advantages**
  - Adjustable
  - Design flexibility

- **Disadvantages**
  - Misadjustable
  - Higher initial cost
Balance By Design

- Advantages
  - No misadjustment
  - No blast gates to wear

- Disadvantages
  - Higher airflows
Why We Need Duct Velocity

- Used to size the duct correctly
Minimum Duct Velocity

- Vapors, Gasses, Smoke: 1000 - 1200 fpm
- Fumes, Metal Smokes: 2000 - 2500 fpm
- Dry Dust and Powder: 3000 - 3500 fpm
- Average Industrial Dust: 3500 – 4000 fpm
- Heavy Dust: 4000 - 4500 fpm
- Heavy and/or Moist Dusts: 4500 fpm +

Reference: IVM, Page 5-10
Duct Sizing

- Size duct so target transport velocity > target velocity
- \( A = \frac{Q}{V} \)
- \( Q = 350 \text{ cfm}, \text{ target } V = 3500 \text{ fpm} \)
- Duct size = ?
- \( A = \frac{Q}{V} = 0.1 \text{ sqft} \)
- \( A \text{ of 4”} = 0.0873 \text{ sqft}, \text{ 4.5”} = 0.1104 \text{ sqft} \)
- Choose ?
- \( V = 4009 \text{ fpm} \)
Resistance to Flow

- Straight runs
- Elbows
- Entries
- Contractions and Expansions
System Losses – Straight Duct

Straight duct losses (due to friction)
Straight Duct

- \( SP = F_{\text{duct}} \)
- \( VP = (F'_{\text{d}})(L)VP \)

Losses are a function of:

- Length of duct
- Diameter of duct (smaller diameter has more friction)
- Speed of air through the duct

\[ F_d = \frac{(0.0307)(V)^{0.533}}{(Q)^{0.612}} \]
Calculation of Duct Friction Factor

\( (F_d) \) - (fraction of VP per foot of straight duct length)

\[
F_d = \left( 0.0307 \frac{V^{0.533}}{Q^{0.612}} \right)
\]

Duct Friction Factor is proportional to velocity

OR

\[
F_d = \frac{0.4937}{Q^{0.079}D^{1.066}}
\]

.....and inversely proportional to duct diameter (D in inches)
Example

\[ V = \frac{Q}{A} = 2500 \text{ cfm}/0.785 \text{ ft}^2 = 3183 \text{ fpm} \]

\[ \text{VP} = 0.63 \text{ inches w.g.} \]

\[ F_d = 0.0307 \left( \frac{V^{0.533}}{Q^{0.612}} \right) = 0.0307 \left( \frac{3183^{0.533}}{2500^{0.612}} \right) \]

\[ F_d = 0.0188 \text{ VP/ft} = 0.0118 \text{ inches w.g./foot of duct} \]
Other Related Issues

- Can also use 3-eyed chart in vent manual to determine $F_d$
- At one time there were formulae and charts for different duct materials
System Losses - Elbows

Elbow losses (due to turning of the air stream)
Elbow Design: ‘$F_e l$’
Reference: IVM, page 9-51

Recommended: $R/D \geq 2$
Elbows

- “F_{el}” is a function of:
  - R/D
  - Number of pieces
  - Degree of turn (e.g., 45°, 90°)
- 90° called ‘elbows’
- < 90° called ‘angles’ (e.g., 30°, 45°, 60°)
The elbow loss coefficient ($F_{el}$) is a measure of the static pressure loss due \textit{solely} to the change in direction.

Friction loss from the ductwork in the elbow is taken into account in the straight duct ($F_d$) calculations.

Straight duct measurements are taken to the elbow centerline.
System Losses - Elbows

- 90 degree elbow loss coefficients (5 piece):

<table>
<thead>
<tr>
<th>R/D</th>
<th>$F_{el}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>0.24</td>
</tr>
<tr>
<td>2.0</td>
<td>0.19</td>
</tr>
<tr>
<td>2.5</td>
<td>0.17</td>
</tr>
</tbody>
</table>
System Losses – Branch Entries

Branch entry losses
Branch Entry Design ‘$F_{en}$’
IVM: page 9-52

Recommended: $\geq 45^\circ$
Branch Entry Design ‘$F_{en}$’
IVM: page 9-52

$F_{en}$ is a function of Angle of Entry

$30^\circ$ and $45^\circ$ are most common
What is the static pressure loss (in inches w.g.) for the following branch entry conditions:

**Branch Information**

Q = 800 CFM
D = 6 inches
Solution

\[ V = \frac{Q}{A} = \frac{800 \text{ cfm}}{0.196 \text{ ft}^2} = 4075 \text{ fpm} \]

\[ VP_d = 1.04 \text{ inches w.g.} \]

90° entry = 1.00 \[ VP_d = 1.04 \text{ inches w.g.} \]
30° entry = 0.18 \[ VP_d = 0.19 \text{ inches w.g.} \]
Balance at Junction

\[ Q_1 + Q_2 = Q_3 \]
\[ SP_1 = SP_2 = SP_3 \]
What happens if the calculated static pressures of branch 1 and 2 don’t balance at the junction point?

It will balance but…?

Must assure the “higher” static pressure branch is considered the governing static pressure.
Balance at Junction

- If the ratio is less than 1.2, then balance by increasing the airflow through the branch with the lower resistance.

- If the ratio of the governing (higher) static pressure to the lower static pressure is > 1.2, redesign the branch with the lower static pressure.
Adjustment By Airflow

\[ Q_{\text{corr}} = Q_{\text{design}} \]

\( Q_{\text{design}} \) and \( Q_{\text{corr}} \) represent the initial and corrected volumetric flow rate in the lower static pressure branch.
- How do we balance the two branches at point A?

- What is the governing static pressure at point A?

SP = -2.5 in. wg  
V = 3600 fpm  
D = 10”

SP = -2.3 in. wg  
V = 3200 fpm  
D = 6”
Solution

- 2.5” wg/2.3” wg = 1.09
- Ratio is <1.20, so balance can be obtained by adjusting airflow.
- \( Q = VA \)
  - \( Q_1 = (3600 \text{ fpm})(0.545 \text{ ft}^2) = 1962 \text{ cfm} \)
  - \( Q_2 = (3200 \text{ fpm})(0.196 \text{ ft}^2) = 628 \text{ cfm} \)
- \( Q_{corr} = Q_{design} (1.09)^{1/2} \)
  - \( Q_{corr} = (628 \text{ cfm})(1.04) = 655 \text{ cfm} \)
- Governing static pressure = 2.5” w.g. @ point A
How do we balance the two branches at point A?

What is the governing static pressure at point A?

\[ SP = -1.9 \text{ in. wg} \]
\[ V = 3200 \text{ fpm} \]
\[ D = 6'' \]

\[ SP = -2.5 \text{ in. wg} \]
\[ V = 3600 \text{ fpm} \]
\[ D = 10'' \]
Solution

- 2.5” wg/1.9” wg = 1.32
- Ratio is >1.20, so we must redesign the lower static pressure branch (2 to A).
Options Include

- Decreasing duct diameter by ½ or 1 inch.
  - Increases velocity (and velocity pressure), and
  - Increases the hood, duct, elbow, and other losses in that branch.

- Change duct length
- Change elbows or entry angles
- Change hood
- Rebalance
SP at point C is balanced
Still have to maintain minimum duct velocity
Q at C = (Q at A) + (Q at B)
What is V at C?
What if it is higher than V in A or B?
How do we account for the energy to accelerate the V at C?
Accounting for Acceleration

- \( \text{SP}_C = \text{SP}_{A&B \text{ to } C} - (\text{VP}_C - \text{VP}_r) \)

- First find ‘weighted average’ Velocity Pressure for branches going into the fitting
- Next the VP for the new duct section
- Then determine the amount of energy to ‘speed’ the air up to the velocity in the new duct
Accounting For Acceleration

Weighted Average Velocity Pressure \( (VP_r) \)

\[
VP_r = \left(\frac{Q_A}{Q_C}\right)(VP_A) + \left(\frac{Q_B}{Q_C}\right)(VP_B)
\]
Find the correct static pressure (SPc) at point C’

Branch A-C
D = 6”
V = 4075 fpm
VP = 1.04”
Q = 800 cfm
SP\text{ac} = 2.0” w.g.

Branch B-C
D = 5”
V = 3666 fpm
VP = 0.84”
Q = 500 cfm
SP\text{bc} = 2.0” w.g.

Point C’
D = 7”
V = 4864 fpm
VP = 1.48”
Q = 1,300 cfm
SP @ C’ = ?
Need to use the $V_{P_r}$ equation to find the “expected” or weighted average velocity pressure for the two air streams coming together:

$$V_{P_r} = \left(\frac{Q_A}{Q_C}\right)(V_{P_A}) + \left(\frac{Q_B}{Q_C}\right)(V_{P_B})$$

$$V_{P_r} = \left(\frac{800 \text{ cfm}}{1300 \text{ cfm}}\right)(1.04”) + \left(\frac{500 \text{ cfm}}{1300 \text{ cfm}}\right)(0.84”)$$

$$V_{P_r} = 0.96 \text{ inches w.g.}$$
Solution

- The measured velocity pressure at point C is 1.48” w.g., ie, the air has accelerated.
- The energy required to accelerate the air is expressed as an increase in static pressure.

- \[1.48” \text{ w.g.} - 0.96” \text{ w.g.} = 0.52” \text{ w.g.}\]

\[\text{SP}_C = \text{SP}_{A \text{ or } B \text{ to } C} - (\text{VP}_C - \text{VP}_r)\]

- \[\text{SP}_C = -2.0 - (0.52) = -2.52 \text{ “w.g.”}\]
System Components - Transitions

(IVM 9.49)

Issues:
Transition length
Angle of expansion or contraction
Regain for expansions
Contractions and Expansions

- Use for:
  - Fitting ducts into tight places
  - Fit equipment
  - Provide high discharge velocity at end of stack
- Contractions increase the duct velocity – erosion considerations in particulate conveying systems
- Expansions decrease the duct velocity – minimum transport considerations in particulate conveying systems
- Energy loss or regain a function of geometry of the transition piece
Contractions and Expansions

- ACGIH Vent Design Manual Fig 9-d
Contractions

- \( SP_2 = SP_1 - (VP_2 - VP_1) - L (VP_2 - VP_1) \)
- \( L \) depends upon taper angle (0.10 for 20°)

\[ \begin{align*}
VP_1 &= 0.9'' \\
SP_1 &= -3.0'' \\
VP_2 &= 1.5'' \\
SP_2 &= \text{to be determined}
\end{align*} \]
Expansion

- $SP = SP_1 + R(VP_1 - VP_2)$
- $R$ depends upon angle of contraction & dia ratio - 0.25 to 0.92
- Fig. 9-d
Expansion

\[ VP_1 = 1.5'' \]
\[ SP_1 = -3.0'' \]

\[ VP_2 = 0.9'' \]
\[ SP_2 = \]

To Fan
System Losses

How do we use these static pressure loss calculations?

System Static Pressure ($SP_{sys}$). Provides the Fan SP for fan selection.
System Static Pressure

\[ \text{SP}_{\text{sys}} = \text{SP}_{\text{out}} - \text{SP}_{\text{in}} - \text{VP}_{\text{in}} \]
System Static Pressure

\[ SP_{sys} = SP_{out} - SP_{in} - VP_{in} \]
What is the $SP_{in}$?

Add up the static pressure losses on the inlet side of the fan:

- Hood: $-0.81$” w.g.
- Elbows: $-0.25$” w.g.
- Duct: $-0.95$” w.g.

$SP_{in} = -2.01$” w.g.
What is the SP_{out}?

Add up the static pressure losses on the outlet side of the fan:

- Duct_{c-d}: 0.32” w.g.
- Stack head: 0.0” w.g.

\[ SP_{out} = 0.32” \text{ w.g.} \]
$$SP_{sys} = SP_{out} - SP_{in} - VP_{in}$$

$$SP_{sys} = (0.32”) - (-2.01”) - (0.65”)$$

$$SP_{sys} = 1.68” \text{ w.g.}$$