

# Reliable Industrial Ventilation Systems

## Balancing with Dampers

by Steve Guffey, PhD, CIH



West Virginia University  
College of Engineering and Mineral Resources  
IMSE Department/ IH Program

1

## When May Need to Re-Balance

- Original airflow distribution was poor.
- The airflow requirement for one or more hoods changes.
- Added or removed branch.
- You are having a bad day.

2

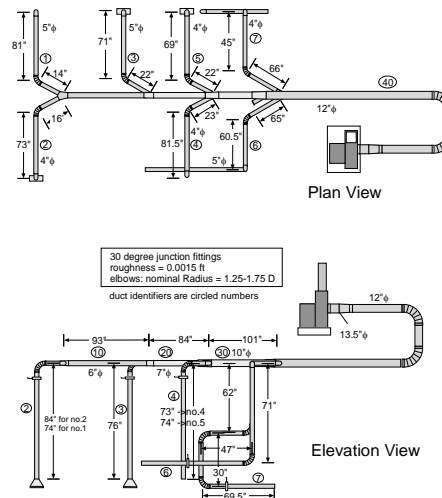
## Problems with using “by design” methods to change airflow distributions

- Must replace components (e.g., elbows) or who ducts).
- Needed changes can be costly and disruptive
  - Reluctant to do. Problems fester.

3

## Use of Dampers in balancing.

- Damper adds resistance to a given pathway.
- Relative resistances determine share of airflow



4

## Goals in Balancing

- Airflows should be high enough to:
  - prevent particulate settling if particulates present
  - ensure adequate control velocities at the hoods
- Excessive airflows should be low to reduce costs.
  
- Total airflow for the system should be minimal, yet no branch airflow should be insufficient (i.e., want  $Q_i \geq Q_{goal_i}$ )
- Ideally, each airflow should exactly equal the goal for that branch duct ( $Q_i = Q_{goal_i}$ )

## Problems with dampers

- *The pressure required at the fan is substantially higher if dampers are used instead of balance by design.*
  - FALSE. Less than or equal to “balance by design” for same airflows and same fan setting.
  - High FanTP only if use dampers to “choke down” the fan airflow without changing the fan speed or if attempt large increase in flow to a branch.
- *Operators and others tend to open dampers*
  - True
  - Lock the dampers with padlocks or weld blades in place.
  - Provide adequate control to reduce temptation.

## Problems with dampers

- ***Plugging is likely due to sticky or stringy contaminants becoming caught on the dampers.***
  - True. Should make maintenance as easy as possible.
- ***Flammable materials caught on a damper could create or exacerbate a fire or explosion hazard.***
  - True in some cases.
- ***If airflow is reduced using a damper, the velocity in some ducts may fall below the minimum velocities***
  - Can happen if the duct diameters are larger than needed.
  - Avoid this problem by replacing over-sized ducts or increasing the target airflows

## *Strategies for adjusting dampers*

---

**Common Method (“Goal Method”)**

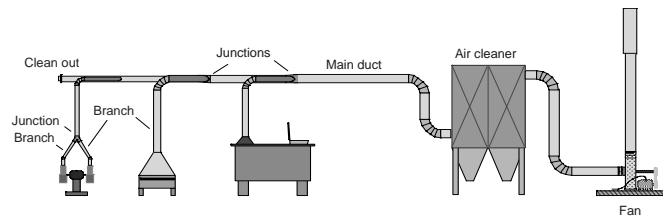
**Proportional Methods (“Target Method”)**

## Common Method (“Goal Method”)

- Procedure: adjust in turn until:  $Q_{br} = Q_{br-goal}$   
[ Note that **fan** airflow falls as each damper is inserted]
- Two possibilities:
  - Run out of airflow before last damper; start over.
  - Or, turns out to be enough airflow.
- For the latter case (enough airflow):
  - For last damper adjusted has correct airflow
  - All others excessive, with those adjusted first the highest.
- After 2<sup>nd</sup> round, airflows closer
- After 3<sup>rd</sup> may be close enough

9

## Why Goal Methods are Painful



- As insert damper in a given branch
  - Branch airflow decreases
  - All other branch airflows increase
  - Total fan airflow drops somewhat
- Adjusting to a goal airflow inevitably frustrating.

10

## Making Goal Methods Somewhat Less Painful

- Compare initial fan airflow to sum of  $Q_{br-goal}$ 
  - If less than 115%, increase speed to 120%
  - If greater than 150%, reduce to 120%
- Don't determine  $Q_{goal}$  during adjustments
  - Determine with Pitot traverse? No way.
  - Determine with  $V_{cl}$ ?  
Don't use  $Q = \text{Area} \times V_{cl} \times 0.9$
- Use VPcl or SP<sub>h</sub>, instead

11

## Making Goal Methods Somewhat Less Painful

- Use VPcl and/or SP<sub>h</sub>

$$VP_{cl-goal} = VP_{cl-open} \left( \frac{Q_{goal}}{Q_{open}} \right)^2$$

$$SP_{h-goal} = SP_{h-open} \left( \frac{Q_{goal}}{Q_{open}} \right)^2$$

Not clear which is better

12

## A Better Approach: Proportional Balancing

- Adjust to same proportions of  $Q_{\text{goal}}$ :

$$Q/Q_{\text{goal}} = C$$

- If successful, may have a narrow range:

$$Q/Q_{\text{goal}} = C_{\text{min}} \text{ to } C_{\text{max}}$$

13

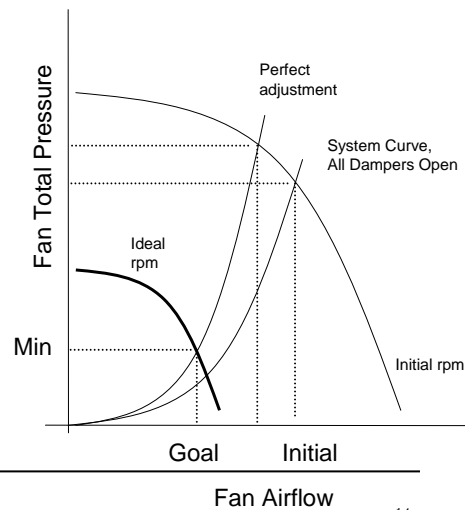
## Proportional balancing

- After damper adjustments

$$\omega_2 = \omega_1 / C_{\text{min}}$$

$$Q_2 = Q_1(\omega_2/\omega_1)$$

- Achieve low FanTP
- But how to adjust to achieve a narrow range of ratios?



14

## Modeling Interactions

- Need to account for change in Fan Q:
  - Predictive model of  $X_{\text{system}}$  as dampers adjusted
  - Predictive model of Fan Q vs  $X_{\text{system}}$
- Need to account for increase in Q for each succeeding damper:
  - Predictive model of all branches and submains
- Computationally difficult
- Consider approximations

15

## Target Method Accounts for Interactions

- Accounting for branch interactions

$$\%k = (n/N)^{0.0445}$$

- Accounting for effect on fan airflow

$$FanFactor = \frac{Q_{fan-open} / Q_{fan-goal} + (\% \min Q_{br-goal})}{2}$$

16

## Target Values for First Round

$$Q_{target} = \%k \times FanFactor \times Q_{br-goal}$$

$$VPcl_{target} = \left[ \%k \times FanFactor \times \left( \frac{Q_{br-goal}}{Q_{br-open}} \right) \right]^2 VPcl_{open}$$

$$SPh_{target} = \left[ \%k \times FanFactor \times \left( \frac{Q_{br-goal}}{Q_{br-open}} \right) \right]^2 SPh_{open}$$

17

## Targets for 2nd Round of Adjustments

- Compute median ratio after first round

$$medSPh_{ratio} = median\{SPh / SPh_{goal}\}$$

$$medVPcl_{ratio} = median\{VPcl / VPcl_{goal}\}$$

- Compute new targets:

$$SPh_{target_2} = SPh_{open} \left( \frac{Q_{br-goal}}{Q_{br-open}} \right)^2 (medSPh_{ratio})$$

$$VPcl_{target_2} = VPcl_{open} \left( \frac{Q_{br-goal}}{Q_{br-open}} \right)^2 (medVPcl_{ratio})$$

18

## Procedure for Target Method

- Full Pitot traverses, SPh, SPend, VPcl for each branch duct with all dampers completely open.
- Adjust dampers using SPh as targets.
- One and one-half rounds of damper adjustments for each treatment.
  - First round based on %k and FanFactor
  - Second round based on median ratios
- Full Pitot traverses after 2nd round to determine final airflow.
- Adjust fan speed
- Determine efficacy of the balancing

Questions?

## Step-by-Step Procedure for Target Method

- 1) Open all dampers
- 2) Do Pitot traverses and measure VPcl and SPh for each branch duct. Compute the “open” damper value of airflow ( $Q_{br-open}$ ) for each branch.
- 3) Compute  $VPcl_{target}$  or  $SPh_{target}$
- 4) Beginning with the branch with the greatest value of  $Q_{br-open} / Q_{br-goal}$  and continuing in decreasing order, adjust each damper in turn until:

$$VPcl = VPcl_{target} \quad \text{or} \quad SPh = SPh_{target}$$

## Step by Step Procedure

- 5) Measure SPh or VPcl again and compute new targets
- 6) Adjust each branch damper so that its measured value equals the 2<sup>nd</sup> target value of SPh or VPcl. Begin with the duct whose ratio is the greatest, followed by the least and alternate between the next highest and the next lowest until roughly one-half of dampers have been adjusted a second time.
- 7) Do a full Pitot traverse for each branch duct to determine the final observed airflows ( $Q_{br}$ ).
- 8) Adjust the fan speed so that the lowest value of  $Q_{br} / Q_{br-goal}$  equals one.

## Airflows after fan speed increased in cfm

Branch	Fan speed High Initially	Fan speed High Initially	Fan Speed Moderate Initially	Fan Speed Moderate Initially	Fan Speed Perfect Initially	Fan Speed Perfect Initially
1	224	235	300	293	338	549
2	222	221	298	298	327	332
3	265	273	383	381	384	561
4	243	244	345	341	390	364
5	260	241	324	315	355	402
6	183	176	284	279	304	487
7	110	109	182	174	185	280
System	1507	1499	2116	2090	2288	2972

23

## Ideal Method Characteristics

- Convenient
  - Easy to take measurements needed to set dampers
  - Few rounds of damper adjustments required to achieve goals
- Simple to follow
- Least energy requirement
  - At least one damper remains completely open
  - Achieves close to ideal distribution (within 3% is VG)

Likely to involve adjusting airflow distribution independently of the fan speed.

24

## Published methods for exhaust system balancing

- Adjust to  $Q_{goal}$ 
  - ASHRAE “proportional” balancing method
  - SMACNA “Stepwise” method
  
- Adjust to Proportion of Total Airflow
  - SMACNA Proportional (ratio) method
  - Guffey Static Pressure Ratio method
  - Guffey  $SP_h$  Goal method (unpublished manuscript)

25

## Published Studies

- Mathematical derivations and simulations:
  - Guffey (Air-Flow Redistribution in Exhaust Ventilation Systems Using Dampers and Static Pressure Ratios. March 1993)
  - Guffey (Damper Adjustment in Vent Systems without Prior System Modeling. unpublished manuscript. July 2004 )
  - Guffey, S. E and Spann J.G. (1999). Experimental Investigation of Power Loss coefficients and Static Pressure Ratios in Industrial Exhaust Ventilation Systems
  
- Experimental evaluation
  - Dodrill (Experimental Validation of the “Target Hood Static Pressure” Balancing Method for Exhaust Ventilation Systems)

26

## The duct system:

- Located in the WVU Exposure Assessment Laboratory
- Full-sized with branch duct diameters of 4" and 5"
- Seven branches, all but two designed to have different resistances to flow (i.e., different combinations of lengths, numbers of elbows, and diameters)
- 20-gauge, galvanized steel ductwork and fittings
- Clamped duct joints; sealed with caulking

27