NURUL "MONI" TALUKDER, P.E., PROCESS BARRON, USA, PRESENTS A COMPARATIVE STUDY OF FLOW CONTROL DEVICES FOR MECHANICAL DRAFT FANS.

FLOW CONTROL

Introduction

Mechanical draft fans (Figure 1) are used to force, induce and boost fluid media through the system duct and components. In the process, these machines consume a large amount of power. Proper understanding of their operation and control is essential. Flow control devices are crucial in this regard because they have a direct effect on power savings in terms of how effectively these devices can control flow and pressure through the fan. This article compares several common flow control devices in order to better understand their effects on mechanical draft fan performance and efficiency.

System load demands

Forced Draft (FD) fans are used to supply combustion air to the process system. The Booster fans are used as inline fans to boost pressure in a system and the Induced Draft (ID) fans are used to exhaust flue gases from the system through the stack and ultimately to the atmosphere. These actions cause pressure loss, i.e. system resistance. Resistance in a process system is primarily composed of two fluid dynamics components: friction losses and dynamic losses. Friction loss is mainly a boundary layer phenomenon and can be expressed by the following empirical equation:[1]

$$h_{friction} = f\frac{L}{d}\frac{V^2}{2g}$$

Where:

h = head loss

f = friction factor

V = velocity

L = duct length

d = duct diameter
g = gravitational force

Dynamic losses are due to the geometrical changes causing directional changes and sudden expansions and contractions of the fluid flow path in a process system. These losses are also known as velocity pressure losses and can be approximated by the following empirical equation:[1]

$$h_{dynamic} = k\frac{V^2}{2g}$$

Where:
k = system constant based on geometry

Figure 1. Mechanical draft machine in a centrifugal configuration.

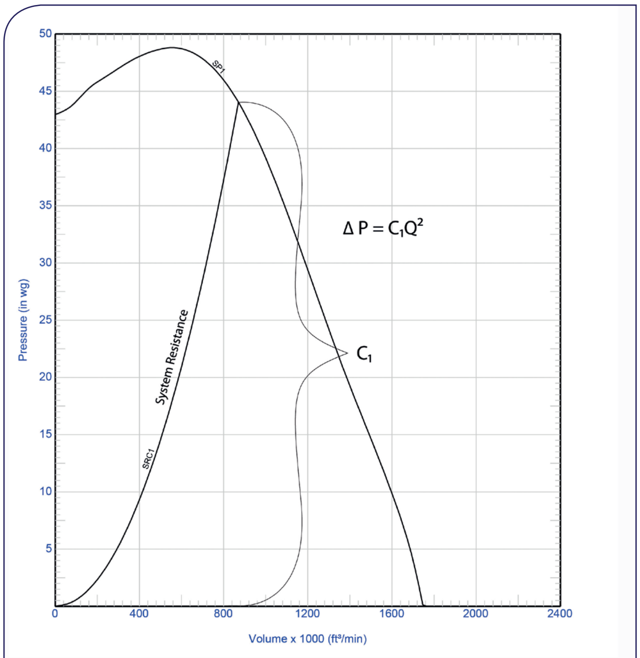

Figure 2. System demand.

This equation is valid for the turbulent flow typical of industrial processes. Combining friction and dynamic losses yields the total system resistance for an air and gas handling system:

$$h_{system} = h_{dynamic} + h_{friction}$$

System resistance and volumetric flow requirements establish the total load demand of a mechanical draft fan system (Figure 2). Safety margins are used over the calculated numbers in anticipation of future contingencies. Typical test block (TB) margins are:

- *Volume: 10 – 15% (acfm)*
- *Static Pressure: 21 – 32% (inches wc)*
- *Temperature: 15 – 25 (˚F)*

Controlling 'power'

Most of the mechanical draft machines in the industrial sectors are powered by constant speed motors. Load conditions for these fans typically vary between 60% and 80%. Motor selection is usually based on test block conditions, which include a healthy margin over maximum continuous rating (MCR), as stated above. As a result, some method of flow adjustment is needed to meet fluctuating load demand. This is typically accomplished by throttling or restricting flow at the fan inlet and outlet with inlet and outlet dampers. While common, these throttling devices are inefficient and waste energy.

Damper dynamics

The integral inlet damper pre-spins incoming gas to reduce a fan's pressure capability. The physics of this is illustrated in Figure 3. The inlet tangential velocity vectors have a direct effect on how a fan develops its pressure. Pre-spinning reduces relative velocity of the inlet streamlines, which in turn reduces a fan's pressure capacity.[2]

$$H = (V_2^2 - V_1^2)/2g + (U_2^2 - U_1^2)/2g + (W_2^2 - W_1^2)/2g$$

Where:
H = Head loss
V = Absolute velocity
U = Tangential velocity
W = Relative velocity

The pre-spinning of incoming gas changes flow performance of a fan and by controlled modulation of incoming gas, a set of secondary characteristics can be created (Figure 4). As a result of this pre-spinning action, power demand is also reduced. The horsepower may vary from one OEM to another, depending on their design specifics. The reported numbers are typically approximated by empirical relationships based on observations and experiments.

On the other hand, outlet dampers are fairly straightforward. They follow the base characteristics of

Table 1. Comparative performance data based on various throttling devices				
	Volume (afcm)	**Static pressure (in. wg)**	**Speed (rpm)**	**Power (bhp)**
Test Block	870 000	44.07	890	6772
MCR – IBD	756 521	33.32	890	5416
MCR – VIV	756 521	33.32	890	5122
MCR – OD	756 521	33.32	890	6400
MCR – VSD/VFD	756 521	33.32	778	4492

a fan and produce no pre-spinning and therefore do not create any secondary set of performance curves. The power demand of an outlet damper can be easily calculated from the following relationship:

$$BHP_{\text{outlet damper}} = (Q \times \Delta P_{\text{outlet damper}} \times K_p)/(CONST \times \eta)$$

Where:
η = Efficiency, %
Q = Volumetric flow rate, ft^3/min
ΔP = Differential pressure across damper, w.c.
K_p = Compressibility constant
CONST = Conversion Constant = 6362
BHP = Brake-horsepower, bhp

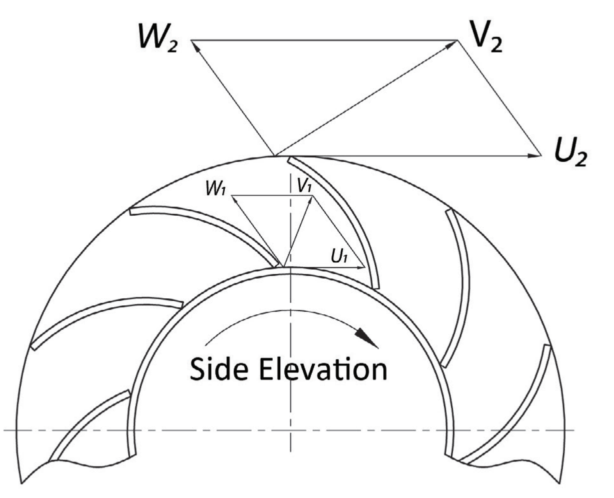

Figure 3. Velocity vectors of a backward inclined centrifugal fan.

Inlet damper controls

Inlet damper controls can be categorised into two types: (1) inlet box multi-louver parallel blade (MLPB) damper controls and (2) inlet variable guide vane (VIV) controls (Figure 5). VIVs, also known as vortex dampers, are typically located in the fan inlet cones. They reduce net effective flow area in the cone with a defined profile that increases the gas flow velocity, resulting in additional resistance. MLPB dampers are located in the fan inlet box with only their blades coming in direct contact with the gas flow. Minimum resistance is experienced when the MLPB blades are positioned in the full open position.

An MLPB damper is typically less expensive than a VIV counterpart for the same size fan. Installation of an MLPB also costs less since some VIVs have to be placed around the shaft and lowered into place. The required torque for an MLPB damper is usually lower than a comparable VIV, which makes the actuator less expensive. Moreover, all of the bearings and linkage assemblies for the MLPB dampers are outside of the duct so they can be easily accessed for maintenance and replacement. Inspection, maintenance and replacement of these components can be performed while the fan is operating. VIV dampers, on the other hand, are often placed inside the fan inlet cones. Access to linkages and bearings is through the fan casing only. This means that VIV components are exposed to the dirty gases, elevated operating temperatures and high gas velocities, and that the inspection, maintenance and replacement of VIV components require the fan to be shut down, causing expensive downtime.

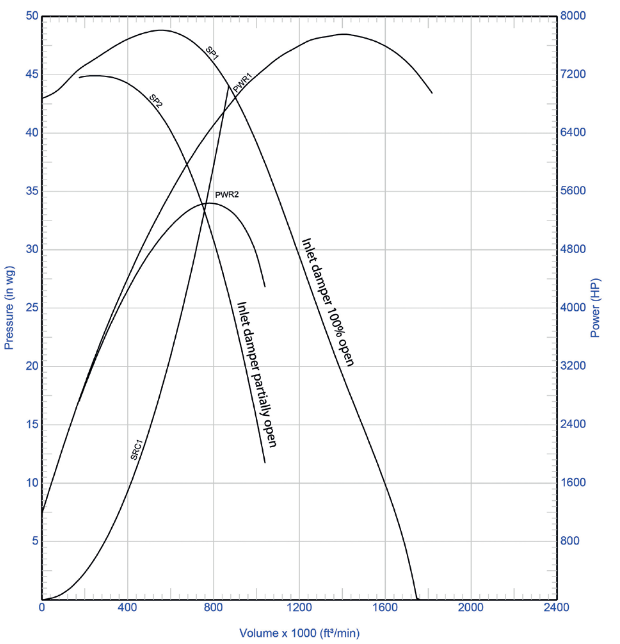

Figure 4. Inlet damper characteristics curve.

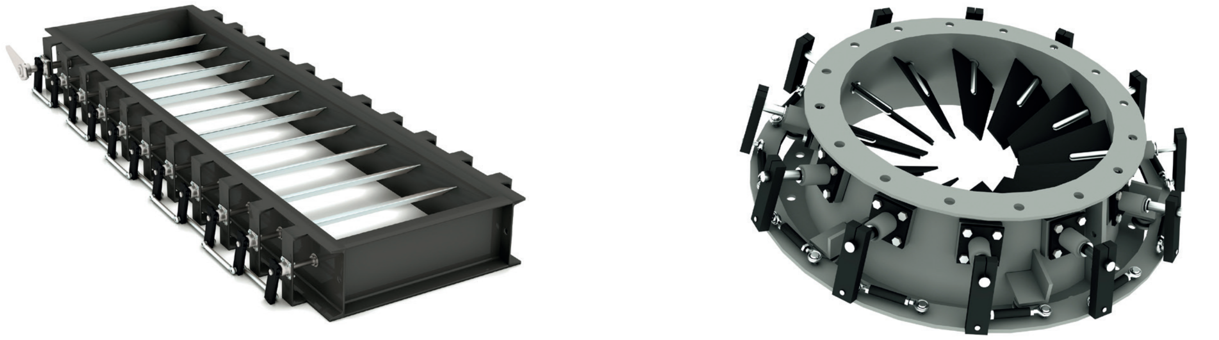

Figure 5. Left: inlet box MLPB damper; right: inlet variable guide vane.

Many consider VIVs worth all this extra hassle because they are generally understood to be more efficient than the MLPB dampers. The main reason for this is because a VIV damper is placed in the inlet cone closer to the eye of the wheel, whereas an MLPB damper is further away. By placing a damper in the eye, greater pre-spin can be induced, thus allowing airflow to enter the eye of the wheel more efficiently. However, on a lot of large industrial fans where there are large volumes and pressures, secondary vortex shedding may occur. To offset this, dorsal fins are added to the vortex dampers to break up the pre-spin effect, reducing the efficiency factor of the pre-spin. Inlet box dampers may be subject to stall conditions at maximum turndown. To offset this, anti-spin baffles are placed in the inlet box.

Variable speed/frequency drives

All restricting type flow control devices waste energy to varying degrees. Fortunately, there is a more efficient option: variable speed/frequency drives (VSDs/VFDs) match driver speed to load demands and thus improve operating efficiency dramatically (Figure 6). There are three interrelated affinity laws based on similarity principles that allow VSDs/VFDs to have such a direct impact on mechanical draft fan performance:

- Volume varies directly with driver speed
  $Volume_2 = Volume_1 \times (Speed_2/Speed_1)$
- Pressure developed varies as square of driver speed
  $Pressure_2 = Pressure_1 \times (Speed_2/Speed_1)^2$
- Power requirements vary as the cube of driver speed
  $Power_2 = Power_1 \times (Speed_2/Speed_1)^3$

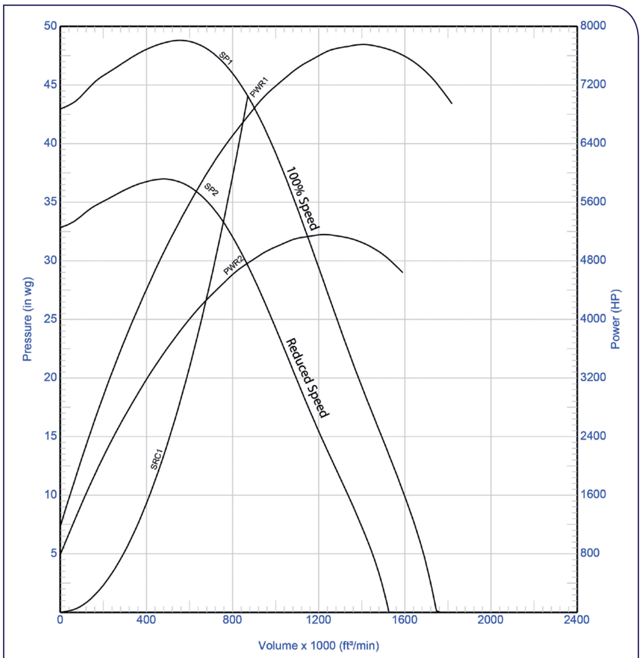

Figure 6. Variable speed performance curve.

Because many centrifugal machines operate at a reduced load for an extended period of time, significant energy savings can be realised by reducing their operating speeds. Speed control can be accomplished utilising (1) a variable speed (VSD), adjustable frequency drive (VFD) and steam turbine drive, (2) hydraulic coupling, and (3) a two speed motor. The selection of each speed control option will depend on project specifics. Often, the speed control has limitations in meeting load demands that are not within the affinity realms described above. Also, with speed control, instability is a concern. Instability can cause serious aerodynamic issues. In order to mitigate these issues and to establish the highest degree of control, a combination of VSD/VFD and dampers are often recommended.

Comparative data analysis

ID fan process data of a typical heavy industrial system was carefully analysed. The tabulated theoretical data below demonstrates performances based on various throttling devices.

This data clearly suggests that the variable speed/frequency drive is the most efficient method to control process flow. Graphical illustrations of the tabulated results have also been presented in Figures 4 and 6.

Summary of findings

Listed below are some of the general advantages and disadvantages of dampers and VSDs/VFDs for controlling air and gas flow.

Damper control

Advantages

- Dampers are very cost effective when purchase price is the only consideration.
- Dampers have no impact on the floor space available in an electrical control room.
- Dampers do not require foundation structure.

Disadvantages

- Dampers are a very inefficient method of controlling air and gas flow.
- Electric motor power factor will vary with the load when the damper is used.
- Dampers generally require more mechanical maintenance than variable speed/frequency drives because they have more moving parts.

VSD/VFD control

Advantages

- Due to significant energy savings associated with speed control, VSD/VFD has a quicker payback than damper control.
- The use of a VSD/VFD will result in the reduction of the motor purchase price because of reduced inertia (if bypass is not needed).
- Terminal power factor at VSD/VFD would be near unity regardless of fan load.
- VSDs/VFDs generally exceed dampers in value when total cost of ownership is weighed over some period of time.

Disadvantages

- The purchase price is higher than for damper control.
- VSDs/VFDs take up floor space in electrical control room.
- Steam turbine drive and hydraulic coupling require foundation structures.

Conclusion

Understanding flow control concepts for mechanical draft fans will undoubtedly help plants and engineers operate their fans at the maximum efficiency rating attainable for their process needs. In doing so, significant energy savings can be realised. A draft fan operating at its best efficiency point will exhibit superior fluid, acoustic and structural performance, reducing housekeeping costs and maximising return on investment.

References

1. WHITE, F.M., 'Fluid Mechanics', 2nd ed., McGraw-Hill, New York, 1986.
2. JORGENSEN, R., 'Fan Engineering', 8th ed., Buffalo Forge Company, New York, 1983.