PERFORMANCE DUCTWORK

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FOREWARD

This paper is intended to introduce the major issues when constructing a system of large ductwork. It is intended for those not so familiar with ductwork design therefore, discussions of mechanics are omitted. Its major purpose is to familiarize the reader with key concepts and terms and to provide a primer for those new to large duct design.

INTRODUCTION

Ductwork is defined as "a system of ducts." For our purposes, we expand ductwork to include the system of supports, expansion elements, reinforcing, insulation, and access provisions required to install and maintain that system of ducts.

So, what is performance ductwork? Performance ductwork uses the most favorable design resulting from an iterative process where key elements of a duct system are all optimized. This process begins with good engineering practice (GEP) and is computational tools like finite element analysis (FEA) and computational fluid dynamics (CFD).

CONCEPTUAL DESIGN

Just as roads and highways connect locations and cities, ductwork connects power and process equipment. At one time, the roads connecting our cities were unsophisticated paths and trails. Today, there are elaborate guidelines regarding right-of-way, grade, turn radii, etc. to which major roadways are designed and constructed. Likewise, certain technical concepts and practices are present in good ductwork design.

Figure 1. Major highways are subject to a strict set of design guidelines to ensure consistent conditions for motorists.

Like many situations we face in life, there are multiple solutions to any problem. To solve these problems, our task is to consider the pros and cons of each available solution and choose what we believe to be the best option. The objective of performance ductwork is to find the optimal solution that satisfies the most variables to the greatest extent possible.

PRACTICAL DESIGN

The shape of the duct must be determined early in the design process. Constructability may dictate that large ducts be orthogonal so they may be delivered in flat panels. Long spans between supports may make round ducts advantageous if they are small enough to be shop fabricated.

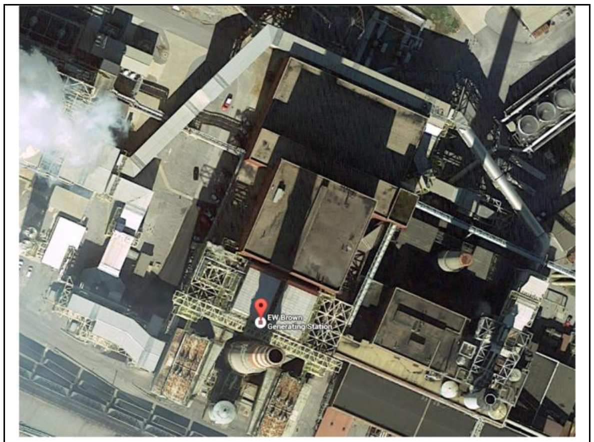

Figure 2. System of Two ducts connecting three boilers to a common scrubber at a utility power plant.

Routing of ductwork is constrained by site conditions including terminal points, obstructions, clearances, and construction limitations. Within these constraints, opportunities may be taken to optimize the design. These strategies include minimizing differential thermal expansion by locating fixed supports symmetrically, minimizing elbows, managing support spans, and minimizing lateral movements in expansion joints.

Figure 3. Large power plant ductwork routed through existing constraints.

LOADS

Design loads for ductwork are shown in Table 1. Gravity, wind, seismic, and live loads for ductwork are typical of most structures. Live loads due to ash are particularly high for solid fuel systems such as coal or biomass. Particular attention needs to be made to the combination of the above loads with operating and excursion levels of pressure and thermal loads. Simultaneously combining excursion levels of pressure and thermal loads with maximum wind and seismic loads leads to unrealistic loading situations overly expensive designs.

Wind
Seismic
Dead
Pressure – Operating
Pressure – Excursion
Thermal – Operating
Thermal - Excursion
Live – Ash
Live – Personnel
Live – Snow

Table 1. Design loads.

SUPPORTS AND REACTIONS

Foundations and support steel for large ductwork systems are usually not supplied by the duct designer. Instead, duct reactions are given to the support designer by the duct designer. It is a mistake for the duct designer to assume the duct supports to be rigid. The flexibility of the duct supports, shown in Figure 4, can contribute significantly to the magnitude of the duct reactions. It is common for the ductwork to be stiffer than the duct support. In these cases, the ductwork may actually be supporting the support steel.

Figure 4. Large power plant duct supported on steel frames.

Sliding supports utilizing Teflon slide plate systems as shown in Figure 5 are used near expansion joints. Fixed supports are used near dampers.

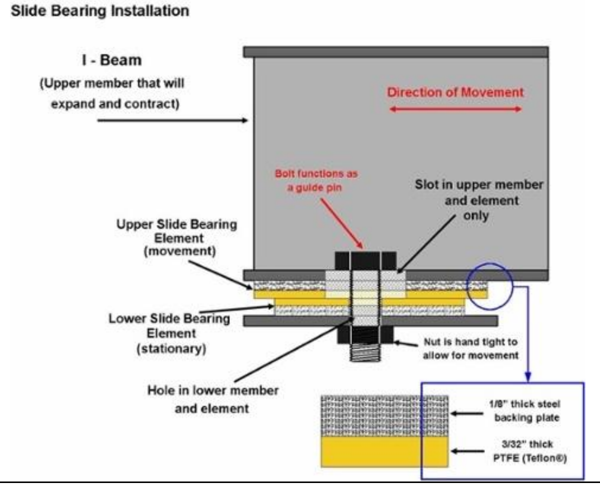

Figure 5. Schematic drawing of a typical slide bearing system. (Image courtesy of Steel Supply Company)

EXPANSION JOINTS

Metal bellows expansion joints transfer considerable loads and contribute significantly to the duct support reactions. Non-metallic expansion joint bellows are preferred since their spring constant is zero. Non-metallic expansion joints are also used for vibration isolation.

Non-metallic expansion joints are highly flexible which allows for concurrent movements without toggles and multiple bellows. Figure 6. shows the four directions of non-metallic expansion joints movement with just a single fabric element.

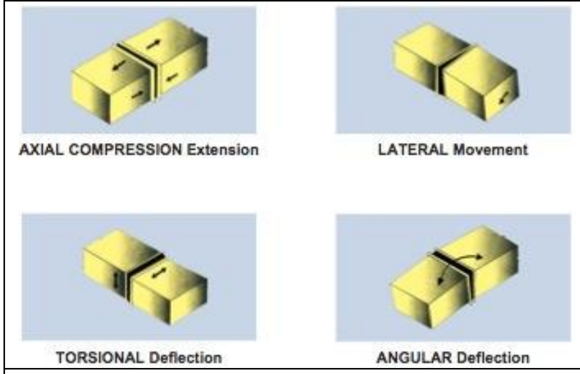

Figure 6. Four directions of non-metallic expansion joints movement.

With the use of Fluoroelastomer and Polytetrafluoroethylene (PTFE) laminated composite products, these expansion joints are corrosion resistant. The joint can be designed for elevated temperature by including an insulating pillow in the cavity between the fabric element and the flow liners shown in Figure 7.

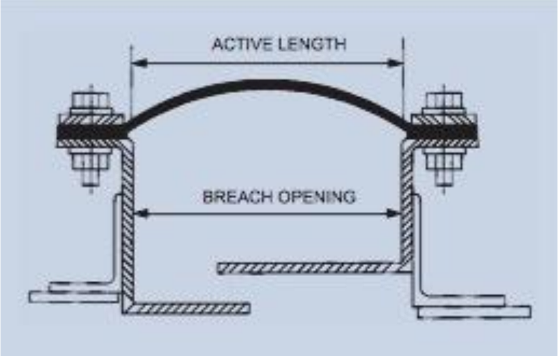

Figure 7. Typical non-metallic expansion joint construction.

Optimizing all non-metallic expansion joints to one active length allows for stocking a single width replacement belt. This replacement belt can be used at any expansion joint location where the gas temperature is below the belt design temperature. Ease of maintenance and low cost of spare parts are an essential part of performance ductwork for the facilities of the future.

DAMPERS

Process gas dampers fall into two categories: isolation and flow control. Dampers vary in their blade and blade seal design, shaft and shaft seal design, as well as their bearing selection and general arrangement. Dampers require maintenance over time to keep them ready for operation. Simple design changes to the dampers can make maintenance simple and keep spare parts low.

ISOLATION DAMPERS

Isolation dampers prevent gas flow and are further categorized by their leakage. All dampers have some leakage due to the tolerance between the damper frame and the blade(s) or blade seals. Zero leakage dampers use pressurized air or gas to create a higher pressure in the seal air chamber than there is upstream and downstream of the damper. This positive pressure barrier prevents process gas from passing the damper.

Dampers styles typically used for isolation include wafer / butterfly, parallel louvers, guillotine / slide gate, diverters, and poppet dampers. Application, leakage, clean or dirty system, space availability for installation and pressure drop dictate the damper style. Wafer / butterfly dampers are characterized by generally round configuration, large, flat blades, (commonly) single shafts, and one-quarter turn (ninety degree) actuation. Figure 8 shows the usual construction features of these dampers.

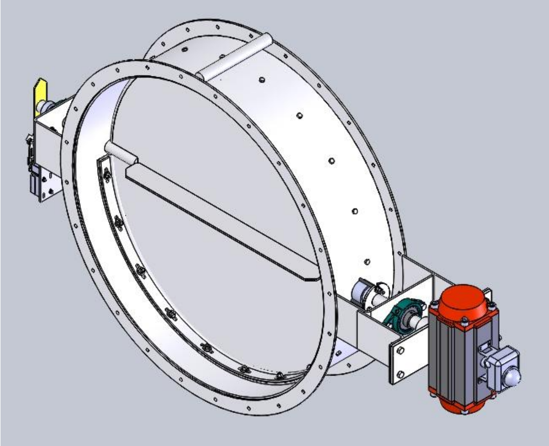

Figure 8. Typical wafer / butterfly damper construction.

Wafer dampers are not desired for flow control; however they are used to balance systems. Figure 9 shows the ratio of air flow versus damper open position for a wafer / butterfly damper. Notice that 80% of the total change in flow occurs within about a 40 degree change in damper position.

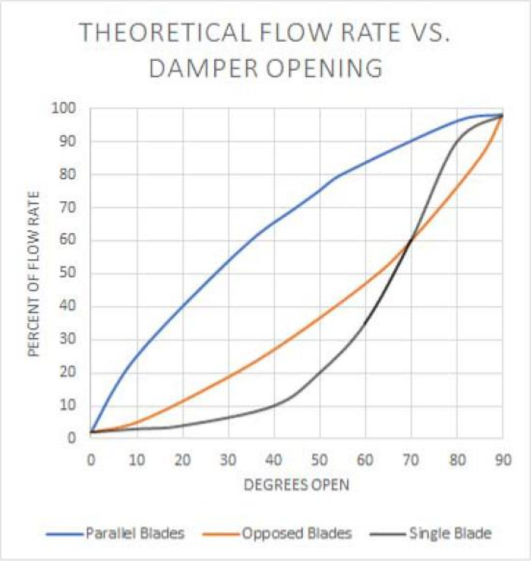

Figure 9. Air flow versus damper open position for parallel louver, opposed blade louver, and butterfly dampers.

FLOW CONTROL DAMPERS

Dampers styles typically used for flow control are opposed blade louver dampers. In fan applications dampers are used to control the pre-spin of air into fans. This is done with radial vanes and parallel louvers. Louver dampers are characterized by generally rectangular configurations with blades spanning the long distance and have an air-foil shape. Louver dampers have multiple shafts with interconnecting linkages, and ninety degree actuation. Figure 10. shows the usual construction features of these dampers.

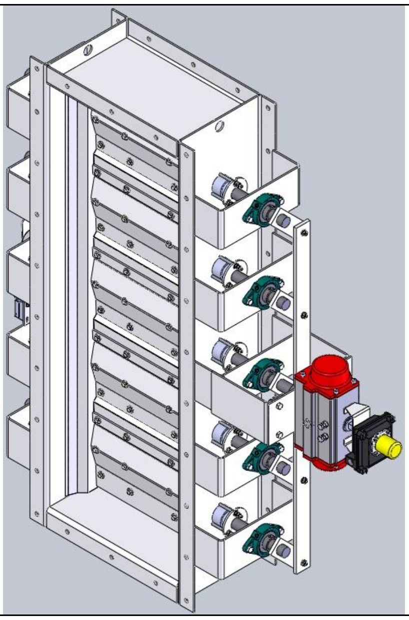

Figure 10. Typical louver damper construction.

Control dampers are used to control flow, pressure, or temperature of a duct system. Opposed blade louver dampers are generally used when control is required. These dampers function by rotating adjacent blades in opposite directions (one clockwise and the next blade counterclockwise). Operating the blades in this manner more gradually (compared to parallel blades, see Figure 9) increases or decreases the cross-sectional area between the blades during operation. Figure 9 also shows the percent of air flow versus degrees open for opposed blade louver dampers. Notice that for opposed blade louver dampers, 100% of the total change in flow occurs within the full 90 degree change in damper position.

DAMPER APPURTENANCES

Shaft bearings are selected as manually lubricated roller bearings or perma-lube sleeve bearings based upon the shaft load and operating temperature. Bearings should be lubricated as required by the bearing manufacture. The dampers should also be stroked or at least slightly jogged every 30 days. The exercising of the dampers helps eliminate any particulate build up or settling which may cause the damper to bind over time.

Packing glands are supplied to eliminate leakage through the frame openings at the shaft penetrations. Dampers should be designed so that packing can be replaced without removal of the bearings or linkage. Bolts used in the packing gland design should be stainless steel construction. Packing material should be the same on all dampers in the in the ductwork system.

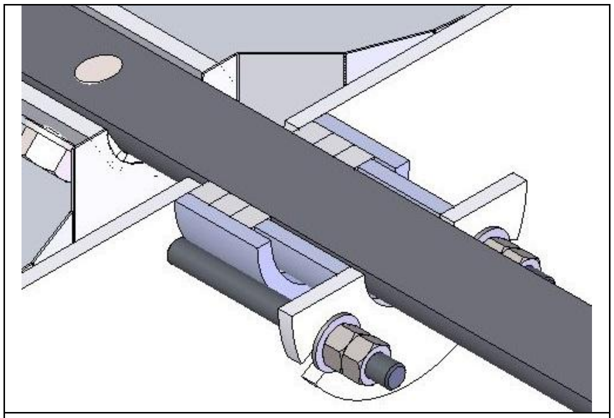

Figure 11. Shaft stuffing box.

Dampers use mainly two different styles of blade seals: metallic or non-metallic, i.e. fabric or rubber. Metallic seals are typically some type of alloy steel. High chrome and nickel alloy seals are used in extremely corrosive applications. Non-metallic seals are used primarily in round dampers and normally are tadpole style. All damper seals should be bolted on where possible so they can be replaced over time. It is not advised to put metallic blade seals on control dampers.

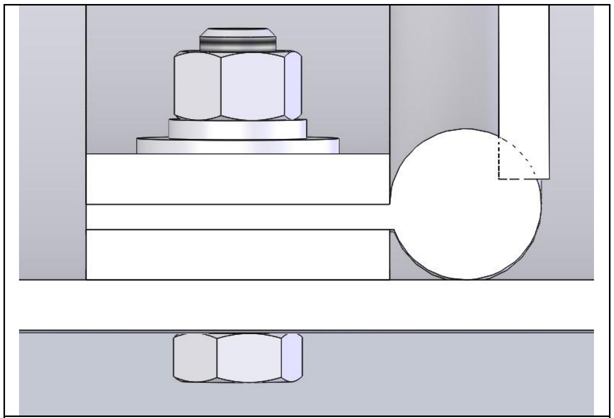

Figure 12. Non-metallic tadpole blade seal.

Dampers can be equipped with many styles of actuation. Power transmission can be via linear or rotary motion. Motive force can be supplied via manual, electrical, pneumatic, or hydraulic drives.

Figure 13. Multi-turn electric actuator (Photograph courtesy of Auma).

Most actuation schemes have the capability to add positioning controls and feedback.

Figure 14. Linear pneumatic cylinder actuator (Photograph courtesy of Parker).

DUCT PRESSURE LOSS

Duct pressure drop is the litmus test for well designed flow patterns in ductwork. Pressure drop is the measure of energy required to move gas through a process gas system and is always minimized in performance ductwork. Computational Fluid Dynamic analysis is used to evaluate duct flow. Performance ductwork will also maintain sufficient velocity to minimize particle fallout in solid fuel systems and provide minimum variability of pollutant load to air pollution control equipment.

Good engineering practice would be to minimize the use of elbows, have all elbows designed with long turn radii, using long, smooth transitions, etc. When CFD analysis reveals undesirable flow characteristics, the designer can iteratively change the GEP parameters or incorporate turning vanes as shown in Figure 15 into the elbows and transitions.

Figure 15. Turning vanes installed in a duct elbow.

When elbows and transitions in ductwork are too compact or too sharp to allow laminar flow, the duct configuration must be changed or turning vanes may be added to redirect gas flow. Preliminary CFD analysis may show areas of zero gas flow or "dead spots as shown in Figure 16. This, of course, is undesirable and may be addressed by changing the duct configuration.

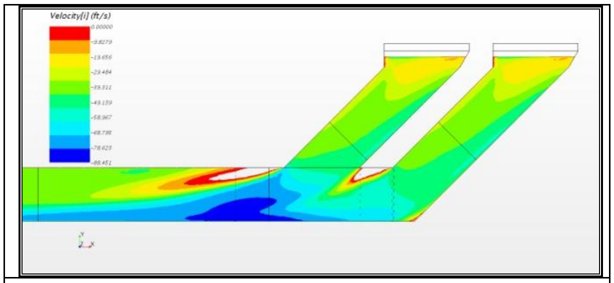

Figure 16. CFD velocity profile showing dead spots void of gas flow (red area represents zero gas velocity).

Preliminary CFD analysis may also show areas of gas flow recirculation as shown in 17. This also is undesirable and may be addressed with a combination of changing the duct configuration and adding turn vanes.

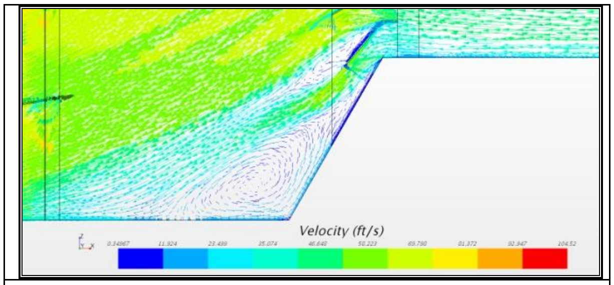

Figure 17. CFD velocity profile showing area of recirculation.

The addition of turning vanes helps produce a uniform velocity profile as shown in Figure 18. This uniform velocity minimizes pressure drop and helps minimize or eliminate particle fall out.

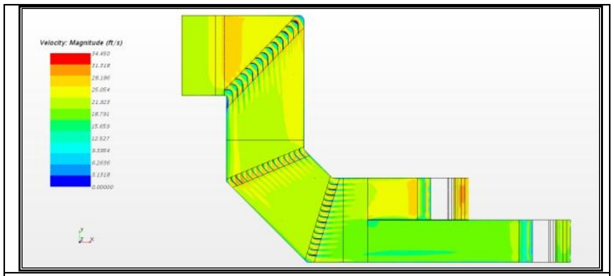

Figure 18. CFD velocity profile showing good use of turning vanes to produce generally uniform flow through duct with multiple elbows. ***Notice the addition of turning vanes.***

Turning vanes as shown in Figure 19 help provide uniform velocity at fan inlets which help ensure maximum fan efficiency.

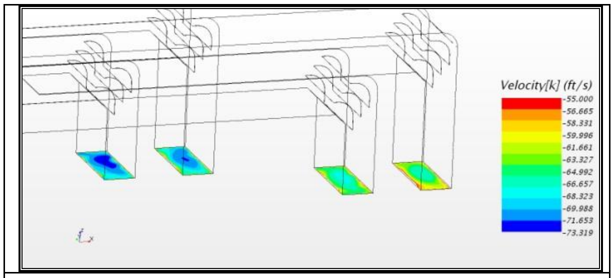

Figure 19. CFD velocity profile showing good use of turning vanes to produce generally uniform flow at four fan inlets.

Flow energy can be regained by using verified evase designs following fans as shown in Figure 20.

Figure 20. Flow energy can be regained by using verified evase designs following fans.

CONSTRUCTABILTY

Very large ductwork is usually constructed as orthogonal sections to best accommodate transit from the factory. Sub-assemblies are assembled on the ground at a staging site and then lifted into place. Because flat sections are more easily fit-up and welded than corner sections, often ducts are shipped in "cee" sections where the corners are made in the factory. This construction results in duct sections that are more rectangular in shape than square but it often suits the design.

Figure 21. Field assembled duct section being lifted into place.

STRUCTURAL DETAILS AND STIFFENING

The duct designer must determine the method of stiffening that best meets the needs of the project. The easiest way to shop and field fabricate the duct is by using internal pipe trusses with pinned end connections at the corners of the duct called chevrons. See Figure 22. These internal trusses will be required at each support location at a minimum. One drawback to this type of stiffening system is the increase in pressure drop due to the gas flow around the truss. The designer must aware of the possibility of vibration in the truss members due to the flow of the gas around the pipe members. Also, since the truss a major component in the structural stability of the duct and it is not visible from the outside of the duct, internal inspections are required to insure that the trusses are in good condition.

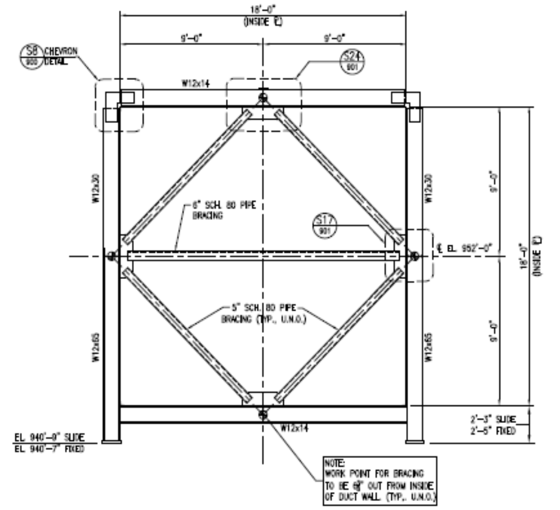

Figure 22. External pinned frame with internal truss inside 18 foot wide by 18 foot high duct.

Another stiffening method is to use rigid frames as shown in Figure 23. This method of stiffening does not any flow obstructions. However, the rigid frames involve full penetration weld moment connections in the corners of the duct which requires more shop preparation and field labor.

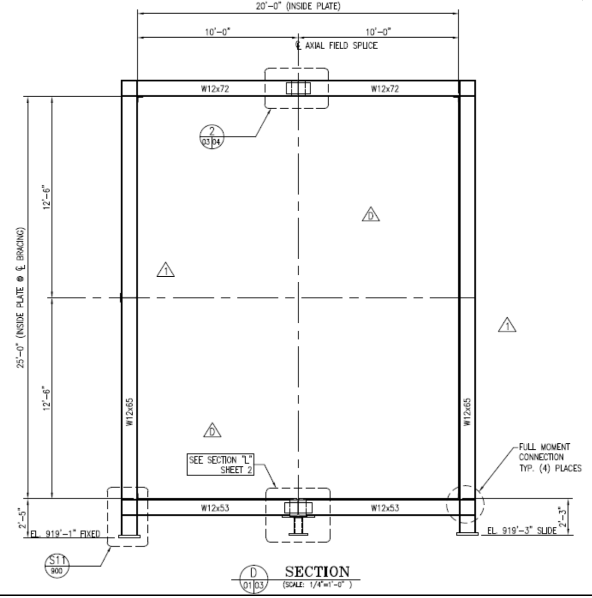

Figure 23. External moment frame with no internal truss of a 20 Foot Wide by 25 Foot High Duct.

ACCESS

Access doors are provided as shown in Figure 24 for the purpose of routine maintenance.

Figure 24. Internally Insulated Access Door For Large Ductwork (Photograph courtesy of Imtec).

CORROSION PREVENTION

Performance ductwork is externally insulated to keep flue gases warm and thereby avoid acid dew point corrosion. Certain "cold spots" can still form in areas where duct attachments like supports, access doors, and instrument ports act as heat sinks. These areas are sometimes lined with alloy metals (anything from type 316 stainless steel to C-276) for a foot or so from the attachment connection as shown in Figure 25.

Figure 25. Large duct section being assembled prior to installation. *Notice the alloy cladding on the expansion joint frame and at the test portson the far side of the duct. Also notice this duct section was shipped in flat panels since the welding is occuring in the corner of the duct.*