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A UNIQUE APPROACH TO HRSG BYPASS DAMPERS

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ABSTRACT

'Soft' start flow distribution, control capability, sealing performance, and safety, were four reasons Oklahoma Municipal Power Authority (OMPA), in cooperation with Black & Veatch and Vogt, installed Dual BiPlane Heat Recovery Steam Generator (HRSG) Isolation and Bypass Dampers from Damper Design, Inc. on the gas turbine outlet at this facility.

The DDI BiPlane damper is truly a unique damper for this application. This design allowed OMPA to have the safety and isolation of a flap diverter while providing the even gas distribution and accurate flow control to the HRSG under startup conditions available from a louver style damper.

The arrangement consists of two DDI BiPlane dampers, one on the inlet to the HRSG and one isolating the stack. Since safety is highest priority, Damper Design utilized an independent lockout type linkage that allows control of the dampers while positively preventing the closure of both gas paths at the same time.

By installing the DDI BiPlane damper, OMPA has the ability to throttle the gas turbine exhaust flow independently to the HRSG and stack. This allows the gases to enter the HRSG with a much more evenly distributed flow pattem and at lower controlled flow rates than with competing designs.

This paper will address the benefits, design, and operating advantages of the use of the DDI BiPlane Damper specifically in HRSG isolation and bypass installations. It is also applicable to other systems where control and isolation with one damper is desirable.

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INTRODUCTION

Oklahoma Municipal Power Authority (OMPA) Ponca City, Oklahoma has recently completed a significant repowering project that increased the generation rate from a steam turbine plant that produced 19 MW to combined cycle capacity of 62 MW. OMPA contracted Black & Veatch to provide engineering services to coordinate this effort.

A GE LM6000 dual fuel combustion turbine with water injection was selected to provide the additional 43 MW of power. The turbine discharges into a bypass stack in the simple cycle mode or, in the combined cycle mode, into a Henry Vogt Machine Co. triple-pressure Heat Recovery Steam Generator (HRSG) with an integral deaerator that has the ability for in-duct firing. The HRSG has a steam output sufficient to operate the original steam turbine at 12 MW capacity unfired and 19 MW with duct firing. The HRSG is designed to cycle on and off daily, as well as serve under base load conditions.

Vogt incorporated the unique DDI Dual BiPlane isolation and bypass dampers on the gas turbine exhaust stream to control flow to the bypass stack or HRSG. These dampers allow independent flow control of the gas turbine exhaust with all of the advantages of a louver damper. Additional benefits include man safe zero leak sealing of the HRSG when the plant operates in the simple cycle mode, or conversely, 100% sealing of the bypass stack for maximum heat recovery.

SYSTEM DESIGN PARAMETERS

System Layout

A General Electric LM6000 combustion turbine discharges into the bypass stack or HRSG as shown in Figure 1. The individual damper assemblies also allow some flexibility in layout for the plant designer that is not possible with other designs.

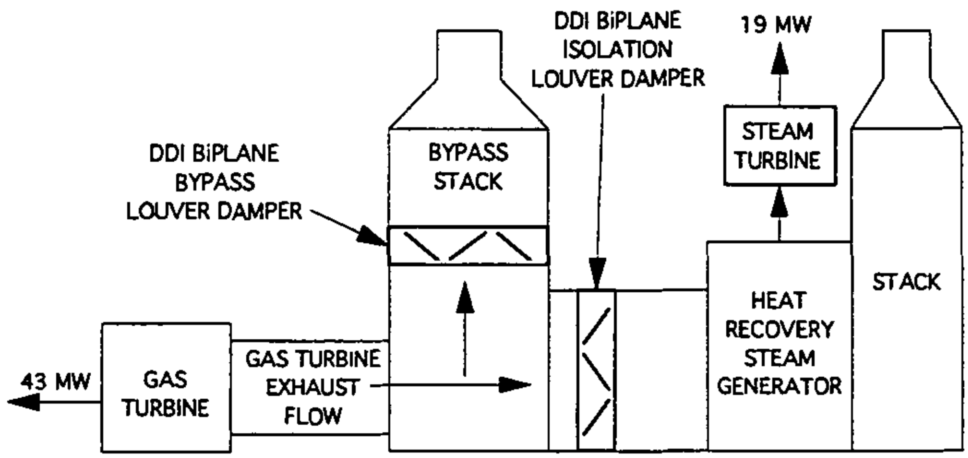

Figure 1 - System Schematic .

DESIGN CONDITIONS AND OPERATIONAL REQUIREMENTS

Specifications

Parameter	Normal	Design	Test
Turbine Exhaust Gas Flow	1,027,921 lb/hr 466,177 kg/hr	1,195,673 lb/hr 542,255 kg/hr	N/A N/A
Turbine Exhaust Gas Temperature	842°F 450°C	1000°F 538°C	950°F 510°C
Pressure	14 in wc 356 mm wc	20 in wc 508 mm wc	14 in wc 356 mm wc
Through Leakage (Closed)	Zero	Zero	Zero
External Skin Temperature (Max)	130°F 54°C	130°F 54°C	130°F 54°C

Additional Requirements

(1) The dampers must pass the full combustion turbine exhaust flow to the bypass stack and positively seal the HRSG inlet.

(2) During HRSG startup the dampers must be capable of passing some of the exhaust gas to the HRSG with the remainder going into the bypass stack.

(3) The dampers must pass the full combustion turbine exhaust flow to the HRSG inlet and seal the bypass stack.

(4) The damper manufacturer must guarantee zero damper leakage when closed to either the bypass stack or the HRSG under maximum gas flow conditions.

(5) With the combustion turbine running at full load, the HRSG isolated, and the seal air system operating, the HRSG shall be safe for entry by maintenance personnel, with proper ventilation, and shall meet OSHA requirements for confined spaces.

(6) To prevent simultaneous closing of the HRSG and the bypass damper, a mechanical interlock shall be provided between the HRSG inlet damper and the bypass damper to allow both dampers to be open, and to lock the open damper more than 80° open when the mating damper closes more than 10°. This linkage shall have provisions for padlock protection for maintenance personnel with the HRSG isolated.

(7) The damper must be tested for leakage, deflection, and cycling operation. The leakage and deflection test was performed on one of the two dampers and shall verify zero leakage through the closed damper under worst case operating temperature and pressure.

DDI DUAL BIPLANE DAMPER SYSTEM ADVANTAGES IN HRSG APPLICATIONS

The DDI BiPlane system is configured as depicted below in Figure 2. The HRSG isolation and bypass stack are both fitted with an independently operated DDI BiPlane louver damper. The system is equipped with a safety lockout linkage, dual electric actuators, and each damper has seal air provided for zero leak operation in the closed position.

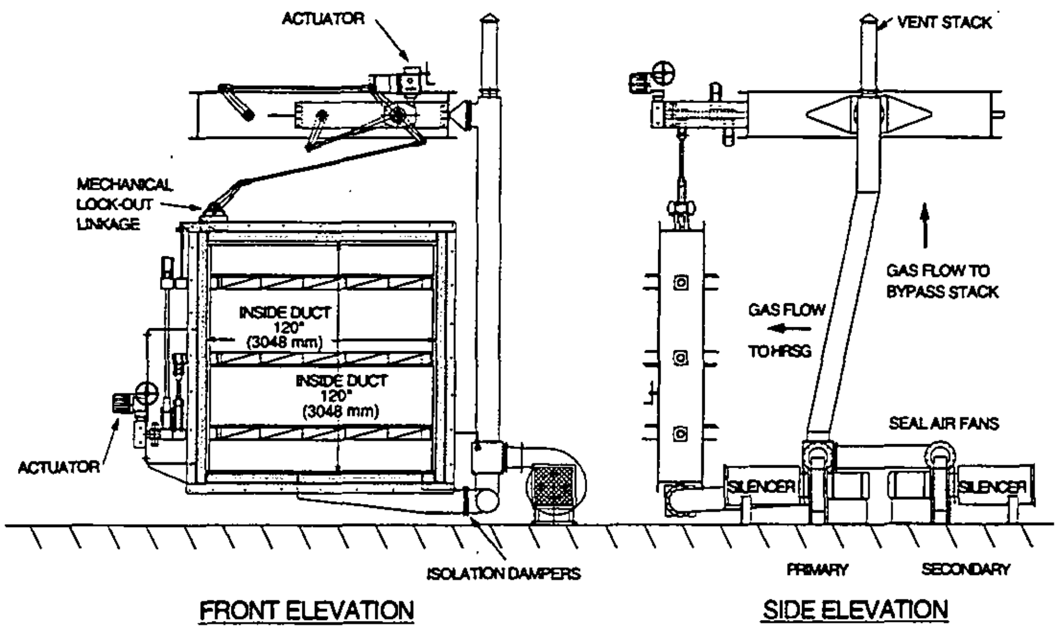

Figure 2 - General Arrangement

Safety of operation is the highest priority for dampers on the outlets of gas turbines. Critical to the acceptance of this arrangement was designing the system such that both dampers were not able to be closed at the same time. This challenge, once solved, would allow the designers, operators, and owners, benefits that are not possible with competing designs.

To insure that both dampers were not able to be closed at the same time, Damper Design engineered a mechanical linkage system that not only prevented simultaneous closure, but only allows operation of the companion damper when the first damper is above 80% open. A mechanical interlock connects the two dampers' linkages such that simultaneous closure is prevented. As shown in Figure 2, the system consists of a driven pin and cam system such that if the bypass damper is in the closed position, the connecting linkage drives a pin into the isolation damper's linkage system that prevents closure. Conversely, if the isolation damper is closed, the bypass damper is prevented from closing by restricting the movement of the pin into the isolation damper's lockout quadrant. This lockout linkage system proved to the engineers and designers that simultaneous closure of both dampers was impossible.

By satisfying the safety design issue, the additional advantages of the louver damper design were able to be realized. These advantages include:

The ability to control the gas turbine exhaust flow into the HRSG from 3% to 97% of the total GTE output. With two independently operated dampers it is very easy to modulate the gas flow to the HRSG. This allows "soft start" capability not possible with competing designs. Figure 3 shows the operation and superior range of flow control into the HRSG with the DDI Dual BiPlane damper system.

HRSG Flow Control Chart
Dampers Modulate Flow from 3% to 97%

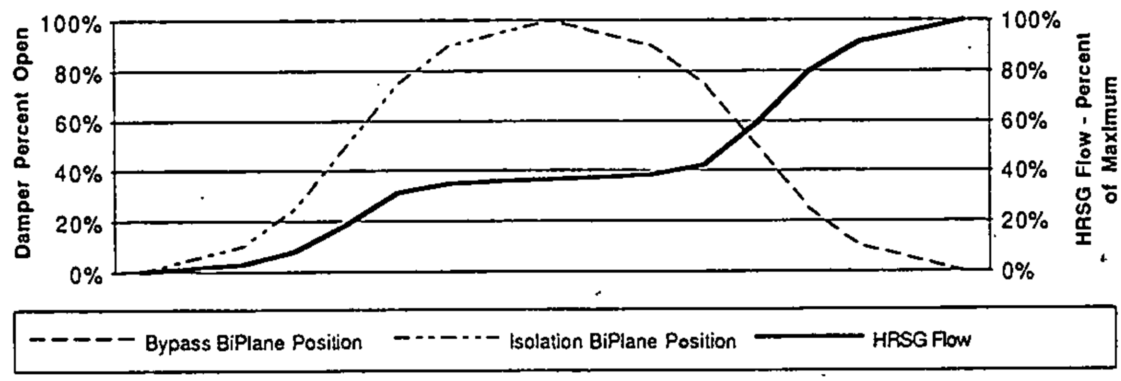

Figure 3 - Flow Control Diagram for DDI Dual BiPlane System

One of the two critical requirements during startup of an HRSG from cold conditions is to maintain maximum gas turbine output. Without a damper system, the only control parameter available is to constrain the gas turbine output and the resultant economic loss of saleable power. With the competing designs, gas flow control is not as precise and startup cannot be accurately controlled, usually resulting in gas turbine output reductions as well. The DDI Dual BiPlane damper system does not constrain the gas turbine output during startup or switching to combined cycle operation thus allowing for "soft start" of the HRSG.

This excellent flow control is now able to be obtained with the ability to distribute the exhaust gases evenly into the HRSG because of the superior flow characteristics of a multiple opposed blade louver damper. This is the second critical requirement of the HRSG startup that is now possible with this system.

The opposed blade louver damper admits the turbine exhaust gas more uniformly into the HRSG. This results in uniform heat adsorption and even expansion of the boiler tubes over the full startup cycle of the HRSG.

Uneven flow distribution, particularly bottom distributed flow in a top supported vertical tube HRSG, results in vibration and deflection in the tubes. These thermal and mechanical stresses can cause fatigue and affect HRSG life.

The sealing system of the multiple blade louver damper is more effective and lasts longer. The smaller blades are less susceptible to progressive thermal distortion which increases the sealing efficiency and reduces the seal air power consumption over the life of the unit.

The damper sealing system also meets requirements for man safe isolation of the HRSG compartment while in the simple cycle mode. When the appropriate damper is closed an automated seal air fan ducting system maintains zero through leakage of the damper that is closed. In the modulating condition, the seal air fan(s) are protected from hot gases by butterfly valves and a vent stack.

Overall, the Dual BiPlane damper system from DDI gives the engineers, designers, and operators what they are looking for from combined cycle electricity generation systems:

- The safety guarantee that neither damper can be modulated unless the companion damper is fully open.
- The ability to "soft start" the HRSG without gas turbine output reduction.
- The flow control to reduce the strain on the HRSG and extend the longevity of the components during HRSG startup.
- The zero leak capability to maximize steam output by eliminating gas turbine leakage to the bypass stack when in the combined cycle mode.

DDI DUAL BIPLANE DAMPER CONSTRUCTION FEA TURES

General

The BiPlane dampers are each 130 inch (3302 mm) by 130 inch (3302 mm) inside frame with 5 inches (100 mm) of insulation and liner assembly creating a 120 inch (3048 mm) by 120 inch (3048 mm) inside duct dimension. Each damper has three (3) blades utilizing the BiPlane blade design and operate in an opposed fashion on closure for superior flow control characteristics. Each blade has insulation on the upstream side of the blade to reduce thermal transmission and temperature differentials of the two blade skins in the closed position. More details specific to the BiPlane construction are highlighted in this paper. A general arrangement drawing of the installed dampers is in Figure 2 previously shown.

Frame Construction

The damper frame construction is designed to work in unison with the existing ductwork of the system. The 0.5 inch (13 mm) thick A-36 carbon steel frame utilizes a bolted flange for easy connection to the surrounding ductwork. The damper is welded to the inside of the liner using a seal plate for added atmospheric leakage protection. To meet the 130°F (54°C) maximum skin temperature as required in the specifications, the frame is lined with 5 inches (127 mm) of Fiberfrax board refractory. All liner sections are constructed from A-387 Grade 22 which is selected because of its superior performance at elevated temperatures. To allow the liner and frame assembly to move in relation to each other without buckling or separation, the liner is assembled with expansion slots to eliminate warpage and is attached to the base frame using stainless steel attachment pins in slotted holes that allow for movement independent of the frame. The liner detail is shown in Figure 4.

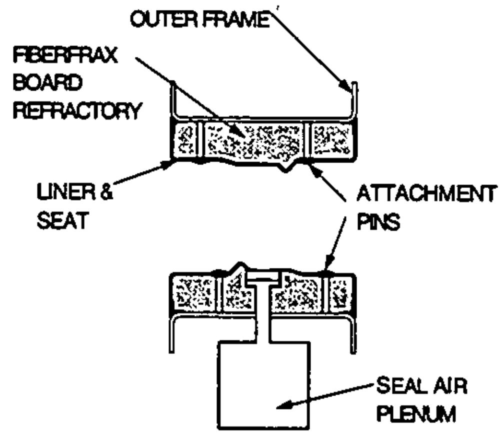

Figure 4 - Frame Insulating Liner Detail

The liner also incorporates the top and bottom blade tip sealing surfaces. They are formed into the metal plate for structural rigidity and provide smooth sealing surfaces for the contact of the flexible seals mounted to the blade tips.

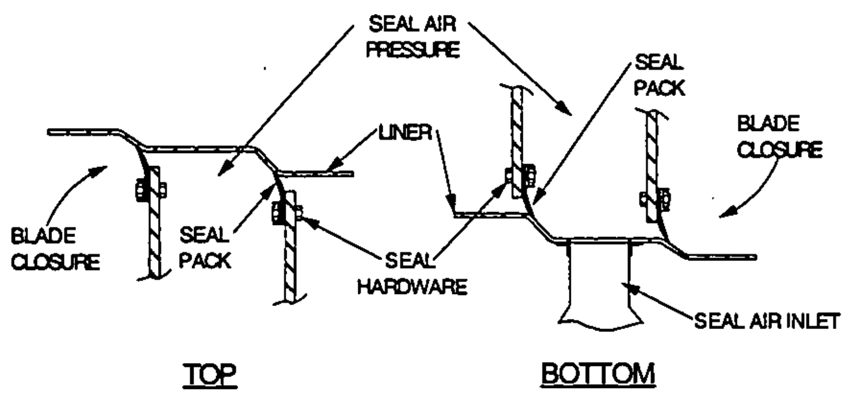

Figure 5 - Blade Tip Sealing to Liner Detail

Integral with the liner are the slots for the introduction of the seal air. When the damper blades are closed, the seal air is supplied at a pressure above the surrounding duct pressure which insures zero leak of flue gas to the downstream side resulting in a "man-safe" environment.

Blade Tip Seals Use the DDI Flexible Seals to Reduce Seal Air Requirements.

In the constant effort to allow blade expansion and contraction without opening leak paths for seal air, Damper Design uses the flexible seal pack to provide sealing for the blade tips. These seals are used on the upstream and downstream edges of adjacent blades and are bolted to the blade edge as shown in Figure 6.

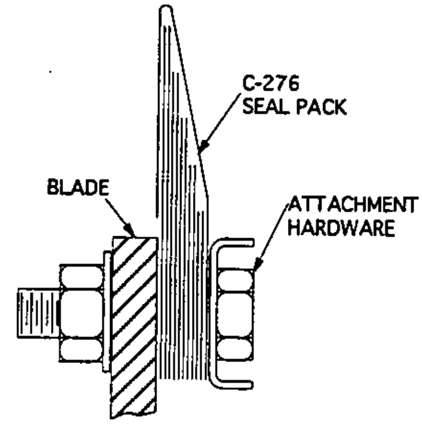

Figure 6 - Multiple C-276 Leaf Spring Seal Design

The flexible seals are manufactured from Hastelloy C-276 which has excellent heat resistance along with the mechanical ability to deform under loading without bending. The seal packs are designed and manufactured to provide progressive sealing forces under all loadings, similar to a leaf spring design used in automotive applications. All seals, except the trailing blade face seals, are pressure loaded into the sealing surface to enhance sealing and positively prevent flutter. The higher the seal air to duct differential pressure, the tighter the seals conform. See Figure 7.

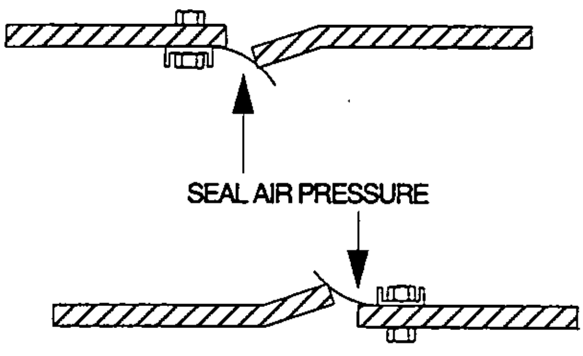

Figure 7 - Blade Tip Sealing Detail

The sealing is very reliable because the seats are self cleaning and the closure does not require precise seating. The flexible seals make up for the movement of the blades and frame while being pressure loaded into the seating areas whether it is the blade tip or liner surface.

The superior sealing system of the DDI BiPlane and its ability to allow very tight tolerances to be maintained under expansion and contraction of the system saves the customer money by minimizing the use of seal air while maintaining "zero leak" safety.

Jamb and Side Seal Construction Minimizes Leak Paths

The blade tips are only one possible leak path that must be minimized to reduce seal air requirements. It is also necessary to maintain close sealing tolerances at the sides of the blades between the blade ends and the liner. Damper Design utilizes a jamb seal system that allows for blade movement while maintaining constant close tolerance clearances.

This jamb seal also uses an alloy C-276 multiple leaf spring seal pack to provide force which loads the jamb seal into the blade as shown in Figure 8.

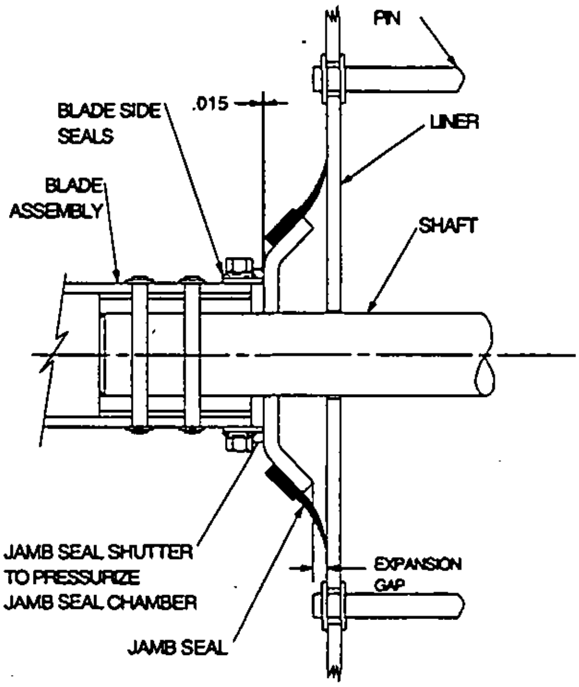

Figure 8 - Frame to Blade Jamb Seal Assembly

The jamb seal loads the blade end by using the natural spring rate of the flexible seal pack. The pack is designed to move in response to blade expansion and contraction while maintaining a constant force on the blade end. In this way the gap between the blade end and the jamb seal is always held constant regardless of the expansion of the blade. The elastic range of the jamb seal allows sufficient blade movement to accommodate the rapid thermal expansion encountered during a turbine start up.

The small clearance between the ends of the blade assembly and the jamb seals is closed by the installation of side seals. These side seals are bolted to the blade and are factory set to a predetermined clearance and provide a minimal leak path for the seal air.

Shaft and Bearing Design

The engineering features that DDI incorporates into all of the products is continued in the bearings and shafts. The shaft packing and bearing system are a function of the design requirements and the service. The DDI standard bearing system used in this application (DDI Style 'B') uses carbon packing with a purged lantem ring to prevent exposure of the carbon components to corrosion and temperatures above the 753°F (400°C) oxidizing temperature. The bearing is a close-coupled self aligning flange block bearing assembly with a high temperature insert. Figure 9 shows the packing and bearing assembly.

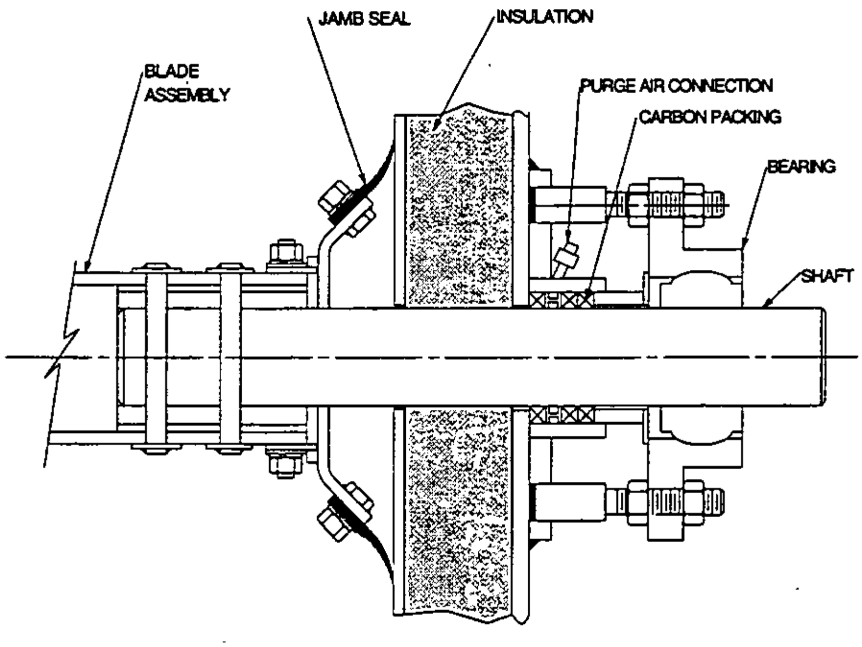

Figure 9 - Shaft and Bearing Detail

This design does not require external lubrication that can attract dirt and abrasives while allowing shaft movement in both the rotational and axial directions.

The shaft material, for this application, is 3 inch (75 mm) diameter 17-4PH stainless steel that is designed to have reached only two-thirds (2/3) yield at the full stall torque of the actuator. The shafts are pinned to the blade hubs which are welded to the structural blades of the BiPlane Damper.

BiPlane Parallel Blade Design is a Structural Component

The BiPlane damper gives the function of a double louver damper in considerably less space. It is the unique design of the dual skin blade assembly that mounts to a single shaft that gives this design superior function at a lower cost.

The blade itself is a truss design that maximizes the rigidity needed in a louver blade. For the same thickness blade assembly and skins, the BiPlane is as much as three times as stiff as a stressed skin airfoil louver blade. This application uses A-387 Grade 22 blades 0.25 inches (6 mm) thick with 0.385 inch (10 mm) thick Z bar truss members assembled as in Figure 10.

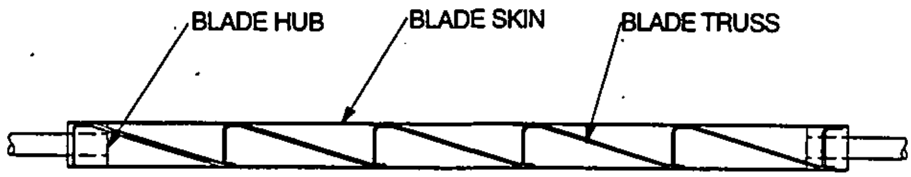

Figure 10 - BiPlane Blade Design

The truss blade design allows this damper to operate with rapid temperature changes such as those experienced in HRSG isolation and bypass service. The trusses permit each blade face to expand and contract as the temperatures change without causing progressive thermal distortion. The blade tip seals and jamb seals then seal over the open area when the blades are closed.

The blades are insulated on the upstream side to reduce the thermal losses across the closed damper. The insulation is covered, top and bottom, by stainless steel insulation pans that are pinned to the blade skins for relative movement.

Another feature of this design is the large open area remaining for flow. Over 90 percent of the duct area is open when the blades are open. In typical HRSG installations with duct velocities of 8,000 feet per minute (40 meters per second), the pressure drop across the open blade is less than 0.2 inches (5 mm) water column.

Safety Interlock Mechanism

Safety is a major concern in any damper system, particularly on the outlet of a combustion turbine. Damper Design meets the customer specifications for safety by incorporating a "cam and plunger" interlock system that will not allow the movement of one damper unless the other damper is within 20° of open. This system guarantees that both dampers can never be closed at the same time.

When the plant desires to switch from simple cycle operation to combined cycle the bypass damper remains at 100 percent open. The isolation damper then can be independently modulated at the operators' discretion to allow for a controlled "soft" start of the HRSG. The bypass damper cannot be closed during this operation because the interlock system will not allow the damper to close. The rate of hot gas input to the HRSG can be controlled while maintaining superior flow distribution across the inlet of the HRSG, (at about 30% of full load).

Once the isolation damper has reached the open position, the bypass damper is able to be gradually closed by the plant operator to increase the flow of exhaust gases to the HRSG. It is modulated to the fully closed position as required to continue the "soft" start up of the HRSG.

Seal Air System

The seal air system is integral to the ability of the system to guarantee "zero" leak through when closed. In this system, two (2) 140 percent fans were provided to maintain seal air to the damper in the closed position. A total of five (5) seal air fan dampers were provided to control seal air flow and protect the fans. Each fan discharge was supplied with a butterfly damper to isolate it from the seal air manifold. Each seal air duct on the damper has an inlet butterfly damper. A bypass stack was included with a damper to protect the fans when no seal air was required by allowing ambient air to be drafted through the fan inlets.

Upon closure of either damper, as indicated by limit switches on the damper actuator, the inlet damper to the seal air chamber opens and the vent stack damper closes to provide seal air to the BiPlane blade cavity created by the closure of the blades and the sealing of the flexible seals.

The seal air pressure is always maintained above the duct pressure to guarantee "zero" through leakage. Seal air consumption is maintained at very low levels to minimize the power costs associated with conveying air. Over the life of a project, seal air consumption differences can be a significant place for cost savings. Customers should evaluate the cost of the seal air when comparing damper manufacturers proposals.

DAMPER PERFORMANCE VERIFICATION TEST

Manufacturer's Tests

The specifications issued by Vogt stated that at least one damper be tested under worst case operating conditions of temperature and pressure. The parameters to be guaranteed were to verify zero leakage through a closed damper, blade deflection at temperature and pressure, and satisfactory cycling operation both hot and cold.

These rigorous test requirements were able to be demonstrated to the customer representatives at Damper Design Headquarters in Bethlehem, Pennsylvania, USA.

The test set up is shown in Figures 11 and 12. The testing rig was designed to provide temperature and pressure control on the upstream side of the damper while, at the same time, allow accurate flow metering for seal air flow upstream and downstream of the damper.

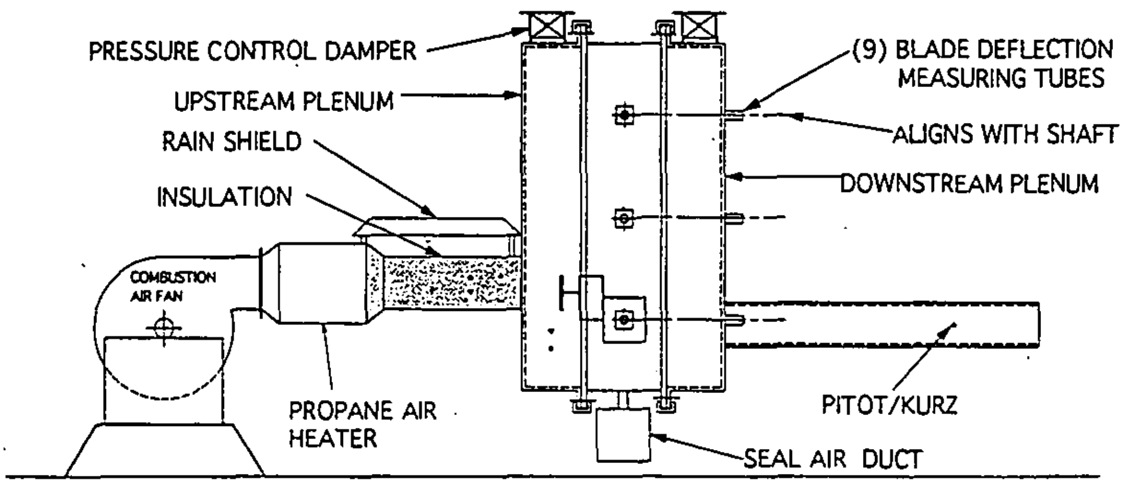

Figure 11 - Test Set Up for Isolation Damper Testing - Elevation View

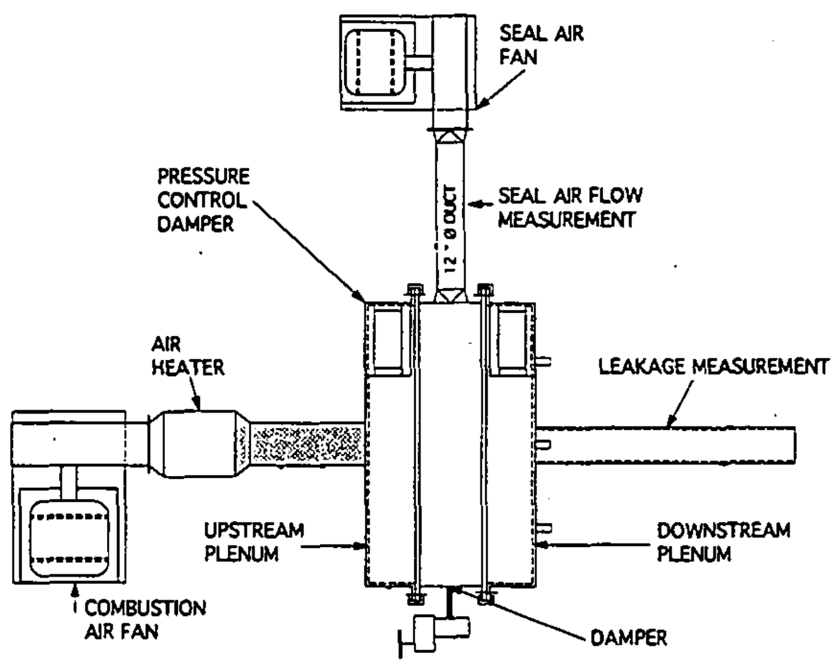

Figure 12 - Test Set Up for Isolation Damper Testing - Plan View

A propane fired air heater discharged into a plenum outfitted with a distribution plate for even temperature control. Because there was no leakage through the closed damper blades, pressure control was done by venting the hot gases through a modulating damper at the top of the plenum, downstream of the distribution plate. The flow testing results are listed in Figure 13.

	Isolation	Bypass
Actuator Full Load Amps	4.10	4.10
Average Run Amps	3.41	2.75
Actuator Locked Rotor Amps	30.50	30.50
Average Starting Amps	24.40	24.40
Spec'd Operating Time (Secs)	30.00	30.00
Ave Operating Time (Secs)	29.71	29.21
Spec'd Seal Air Req'd (ACFM)	2,581	
Ave Seal Air Req'd (ACFM)	2,378	

Figure 13 - Flow Testing Results

The testing specifications also required that blade deflection under pressure of 14 inches (355 mm) water column be measured. This was accomplished by opening ports outfitted into the back plenum and measuring reflection before and after temperature and pressure conditions were met.

The results show that all specified parameters were met or exceeded under actual operating conditions of temperature and pressure. Visual inspection of the damper was also done during this testing which showed that even under severe temperature variations, very similar to actual operating conditions, the system performed better than required. The test procedure called for testing through ten (10) complete cycles and the test was concluded after only five (5) cycles.

In Service Tests

Even the best testing at the factory is not necessarily an indication of how the unit will perform in the field after installation. This section will discuss some early, but promising results of actual operation.

OMPA has been operating in the simple cycle mode since June 1995. During that time the bypass damper has been permanently in the open position. The isolation damper has been permanently closed with a blanking plate on the downstream side to completely isolate the HRSG area during completion of construction from the operating combustion turbine. During this period the system is started at 8 AM and shut down each evening about 10 PM.

In August 1995 the plant removed the blanking plate from the downstream side of the isolation damper to prepare for the future operation of the HRSG. There were no immediate plans to open the damper, but the zero leak characteristics could be checked.

The unit has temperature thermocouples only five (5) feet (1.5 m) downstream of the closed isolation damper. We were able to check these temperatures before and after combustion turbine start up on August 22, 1995. Refer to Figure 14 for a summary of the negligent temperature increases that verify excellent sealing capability. After 6 hours of gas turbine operation, temperature rise downstream of the closed isolation damper was only 19°F (11°C).

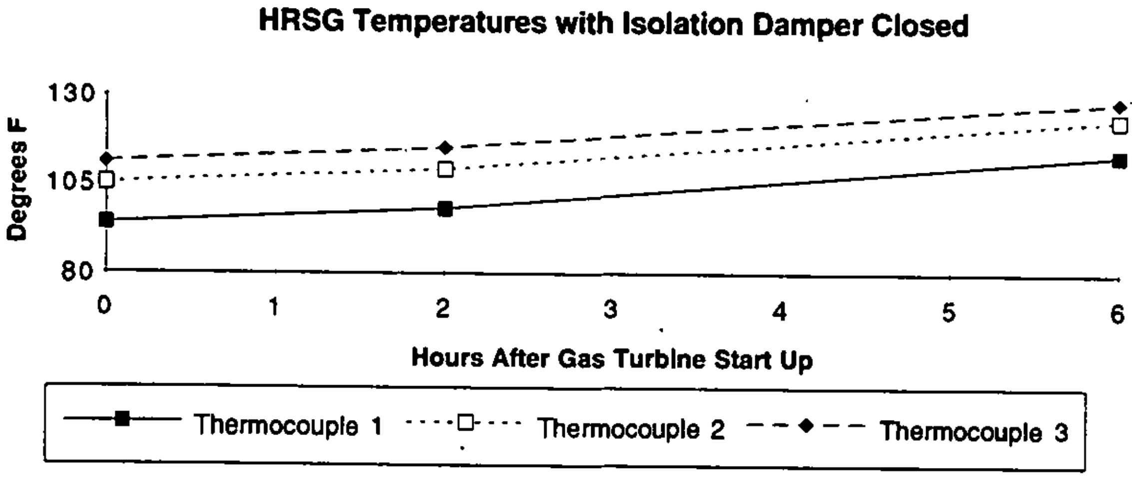

Figure 14 - On-line HRSG Temperatures - Isolation Damper Closed

These readings are an indication that the unit is sealing very effectively when the HRSG is isolated. During this time the seal air system is functioning and the Bypass Damper is open.

Continued testing will be done to confirm operation as the units are cycled more and also when they are switched to the combined cycle mode after commissioning the HRSG.

Conclusions

This paper has highlighted the application, design, and function of the BiPlane Damper from Damper Design, Inc. There are many benefits in this system. These are tabulated below:

(1) The BiPlane Damper provides isolation and control in one damper.

(2) The BiPlane damper provides the safety and isolation of a flap damper using a independent lockout type linkage that positively prevents the closure of both dampers at the same time.

(3) The HRSG will benefit from extended life because the BiPlane Damper provides the accurate flow control of a louver damper with the even gas distribution important to prolonging HRSG life when starting the unit.

(4) The combustion turbine will be able to operate at full load during the switch from simple cycle to combined cycle operation increasing output.

(5) The BiPlane Damper is thermally elastic to allow unrestricted use on rapid temperature swings.

(6) The BiPlane has the most rigid louver blade structure.

(7) The superior flexible seal pack sealing system provides lowest seal air requirements saving additional seal air fan power.

(8) The BiPlane has the lowest pressure drop of any style louver.

In conclusion, the application of the BiPlane Damper system from Damper Design, Inc. is unique for combustion turbine exhaust gas isolation and bypass service. There many engineering features of this system will extend the life of the HRSG because of the ability to provide a "soft" start feature. In addition, the combustion turbine will be able to operate at full load during the switch over from simple cycle to combined cycle generating additional saleable electricity.