Recent advancements in turbine bypass control valves

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In combined cycle power plants, turbine bypass valves are critical and used for a multitude of purposes. This article reviews recent developments with regard to these valves, concerning noise control, thermal cycling, tight shutoff for optimal plant performance and efficiency, controllability and stroking speed.

In combined cycle power plants, the turbine bypass valves are the most critical of any valve in the plant. The valves are used for a multitude of purposes. The valves are used for a multitude of purposes. To match steam and turbine metal component temperatures during startup and shutdown to minimize the effects of thermal fatigue to the turbine internals. To allow the combustion turbine generator to remain on line while keeping the HRSG ready for immediate resumption of steam powered generation in the event of a full or partial load rejection. Solid particle erosion to the steam turbine components is reduced. Independent operation of the HRSG and steam turbine is also ensured. If the turbine bypass valves fail to properly operate in most of these situations, the entire plant will trip off line. Many articles and press releases have highlighted the ever-increasing efficiencies possible in combined cycle plants. The 60% efficiency mark is being approached by newer facilities. With the improved efficiency have come increased pressure and temperature demands that affect the selection of valves along with other balance of plant equipment. Along with higher pressure and temperature, the scope of operation of many of these plants has changed dramatically. Initially, many combined cycle plants were built with the intent of base load operation. However, as market demands have changed and the price of natural gas continues to rise, the plants commonly operate in a daily start/stop (DSS) mode. A typical combined cycle plant today can start between 200 and 300 times each year compared with a base load unit that may start only a handful of times during a given year. The combination of higher temperatures and DSS operation has dramatically affected operation of traditional turbine bypass valves. Common issues noted include weld fatigue, poor shutoff and high noise and subsequent vibration. Because of the changing plant operation requirements, the turbine bypass valves must change as well to address the change in operating requirements. A better solution for turbine bypass valves now exists. The latest innovation incorporates proven technologies to address thermal cycling, noise abatement, shutoff and steam conditioning. Conventional turbine bypass valves rely on a combination of a pressure reducing valve and a desuperheater or steam conditioning section. Combining these two functions reduces the overall cost of the bypass function, but ensuring that both work properly is another concern. The TBX style valve offered by Fisher Controls is an example of the most recent technology to address turbine bypass valves. This valve relies on the latest methods of noise attenuation, trim retention, tight shutoff ability and proven water injection.

Better noise control I

One of the biggest issues confronting turbine bypass valves today is noise control. Conventional turbine bypass valves rely upon a series of internal diffusers that dissipate valve noise by staging the pressure drop across the valve. This type of design works well in plants with a limited turndown range. In operation, the diffusers are no different than any other type of fixed restriction. The diffusers are sized to provide the best noise attenuation and pressure staging capability for a given set of conditions. If these conditions vary, the ability of the diffuser to supply the same amount of noise attenuation is altered. While using a series of diffusers to address this helps, it is still difficult to address the wide range of conditions experienced by turbine bypass valves today. When controlling noise, IEC 60534-8-3 references two methods of noise abatement. One method is to lower the velocity of the fluid in the valve trim, thus reducing the turbulence and associated noise generation. The other method relies upon shifting the frequency of the exiting fluid beyond that which can be heard by the human ear or that will cause damage to the piping system. The noise abatement solutions on the market today rely use either method or a combination of both. The flow down approach utilizes the velocity control approach when used at the originally designed conditions, but the flow through the initial control sleeve drastically reduces the peak frequency leading to increased noise. When flowing through the initial control area, the jets exiting into the center of the control sleeve collide creating additional turbulence, thus noise. The downstream diffusers will dissipate this somewhat, but it is still an isolated noise source. In many cases, this noise source can overpower the attenuation provided by the downstream diffusers. In order to address this, the latest turbine bypass valve offering utilizes a 'flow up' approach to achieve the best overall noise reduction. By flowing up through the valve, jet separation is maintained at the trim outlet to prevent interaction that creates turbulent noise. Noise control is becoming a bigger concern as power plants begin are more commonly built nearer to residential areas. The required overall noise levels emitted from a power plant are falling lower, which means that the control valves need to provide lower noise levels. Far field noise (1000 feet) levels of 55 dBA or less are the norm today for many turbine bypass valves. This requires uninsulated valve noise to be well below the traditional 85 dBA limit. This is especially important in plants utilizing air cooled condensers. Air cooled condensers are becoming more common as plants are being built further from prime cooling water sources. Air cooled condensers utilize a thin walled (5/8" or less) duct that carries the exhaust steam from the steam turbine outlet to the condenser located outside of the turbine building. When the plant is in a bypass mode, dumping steam into this thin walled pipe can create substantially high noise levels caused by the generated turbulence as the steam dumps into the condenser duct. In order to provide the lowest noise possible in these types of applications, detailed research has been conducted to determine the effect of turbine bypass valves on noise in these types of applications. This research is especially important since insulating the duct is usually a last resort because of its size. Testing conducted by Fisher Controls has been focused on the effects of dumping steam directly into a large diameter duct. The series of tests looks at the turbulence generated as the steam enters the condenser duct through what is called a steam sparger. The sparger is used to create a back pressure on the turbine bypass valve while also dispersing the steam in the duct and provide additional noise attenuation. Sparger selection in these applications is critical in that it must be sized in conjunction with the turbine bypass valve. This is mainly for optimization of the valve and sparger sizes, but also to ensure that the turbulence and noise exiting the sparger is minimal so not to cause additional noise generation in the condenser duct. Spargers are typically 'stabbed' into the condenser duct, making insertion length critical. If the spargers take up too much area in the duct, the backpressure exerted on the steam turbine increases, which reduces turbine efficiency. The insertion length is also critical from a noise generation standpoint. If the flow passages are located too closely to the duct, isolated areas of turbulence can be generated along the duct wall leading to additional noise generation. Therefore, the insertion length must be managed along with the size of the outlet holes and the spacing between the holes. Since there are typically more than one set of bypass valves, there are a series of spargers inserted into the condenser duct. To minimize the cross sectional area taken up in the duct, the spargers are placed in series through the length of the duct. The spacing of these devices is critical to noise generation. If the spargers are placed too close together, the exit streams from the spargers can combine to create a force that acts perpendicular to the condenser duct causing noise generation and potential fatigue. As discussed previously, IEC 60534-8-3 discusses two methods of noise attenuation; frequency shifting and velocity control. Frequency shifting is accomplished by using a set of trim with small outlet passages. The small passages shift the frequency to a high enough point where it is not audible to the human ear. At this higher frequency, the energy of the system has also been reduced to as to not cause damage to the downstream piping. This method of noise abatement works well, but it is key that there is adequate jet separation at the trim outlet. If the trim outlet passages are placed too close together, the jets will combine to form a larger jet with greater turbulence and a reduced frequency. The higher turbulence and reduced frequency will lead to additional noise generation. This is why spacing of the sparger holes and the sparger themselves are critical to reduced noise generation.

specified theoretical minimum, the localized high velocity generated will lead to turbulence and subsequent noise generation. Coupled with the effect noted above, the jets exiting the trim will not be dispersed evenly. This can cause the exit jets to recombine increasing turbulence and reducing peak frequency. Looking at the left hand model in Figure 1, one can see that the highest velocities, shown in red, occur at the trim outlet and that the exits jet combine leading to additional noise generation. The latest means to control noise uses flow passages that maximize the area used in the valve trim. WhisperFlo is one such example of this type of trim. Specially shaped passages will minimize fluid separation from the trim passages minimizing the space required to achieve a desired level of noise attenuation. In order to control velocity through the trim, the pressure drop must be staged. With compressible flows, a pressure drop equals an increase in volume. To properly stage the pressure drop, an area to allow the fluid to expand and recover must follow a stage. This will minimize the potential for highly turbulent areas in the trim

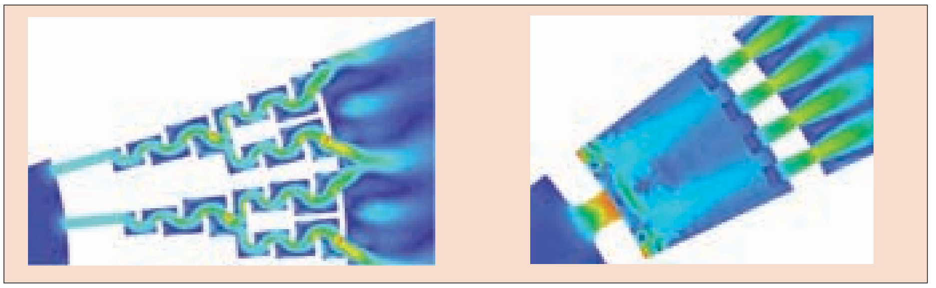


Figure 1: Velocity Profile of Tortuous Path Trim (Left) vs. WhisperFlo Trim (Right)

Better noise control II

The other approach to noise generation is to control the velocity of the fluid and thus limit the amount of turbulence generated. The latest method of noise attenuation available combines the velocity control with the frequency shifting noted above. There are different approaches to controlling velocity. One of the most commonly used methods has been the use of tortuous paths, such as a series of elbows to reduce the available energy. While this technique in principle works well, it requires a lengthy series of elbows to account for the inefficiencies in the method. The velocity profile of flow going through a 90 degree turn yields a wide ranging velocity profile. There will be dead areas with very low velocity and areas of higher velocity as the fluid goes around the bend. While the average velocity may be within a

that can lead to further noise generation. The right hand flow model in Figure 1 shows the recovery area allowed after the initial stage. The outlet passages of the trim must also be specially shaped to minimize fluid separation from the trim, but also to prevent jet combination at the outlet. This is again shown in the right hand model of Figure 1. One factor commonly overlooked in noise reduction trims is the space allowed between the trim and the valve body. If the trim is located too close to the valve body, the exiting jets will recombine to form a highly turbulent zone that will lead to further noise generation.

The effects of thermal cycling

DSS operation can lead to a great deal of thermal cycling in the bypass valves. Temperatures can reach extremes of 1100 degrees Fahrenheit and can drop to low temperatures when the unit is brought down overnight. This can impact the internals of the control valve and can also lead to issues with body and weld connection fatigue. The first thing to consider with thermal cycling is the effect that this can have the valve trim. With the constant temperature chance, the valve internals can continually grow and contract. If these are 'clamped' in place by the valve bonnet, damage can occur to the cage, seat and gasket surfaces due to the growth of metal components. If the parts to continue to grow and contract, they can fatigue leading to premature failure. This can introduce a multitude of problems such as body and trim erosion, trim seizure, excessive leakage, vibration and noise. When any of these issues occur, it can lead to costly trim and body repair or potentially replacement let alone be detrimental to plant performance and availability. To counter the potential for thermal expansion effects, the valve cage is hung from the body to bonnet landing allowing the cage to grow as temperature increases. The trim materials are also closely matched to the body materials in order to prevent the possibility that certain parts could grow at a faster rate than others leading to valve inoperability or premature damage. The other potential for detrimental thermal cycling effects occurs after the pressure reducing section of the valve. Once the pressure drop is taken through the valve trim, the steam conditioning function must take place. Spraying 'cold' water into the flow stream can have serious effects if not done properly. Some of the problems that can occur with mis-applied steam conditioning include water hammer, piping erosion, pipe weld fatigue and condenser damage due to inaccurate temperature readings. In order to properly account for potential issues, extensive use of computational fluid dynamics (CFD) software is used to model the effects of water injection into the system. This tool is used to optimize the placement, insertion length and number of the nozzles into the outlet of the valve to assure proper spraywater mixing and to minimize straight pipe length requirement. Figure 2 shows a CFD model with the steam temperature profile after spray water injection. Red indicates the area of highest temperature and light blue indicates the lowest temperature. To properly set the downstream straight piping requirement, CFD work is also done to model the droplet size and atomization properties of the spraywater. If an elbow is installed too close to the valve, erosion of the elbow can occur and water fallout is possible. This will increase the pipe length required for adequate atomization. If the piping system is not ideal for a combined valve and steam conditioning section, the steam conditioning section can be broken away from the valve to be installed somewhere downstream.

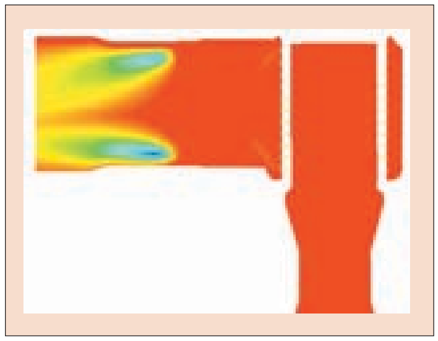


Figure 2: CFD Model of Steam Temperature Profile (left)

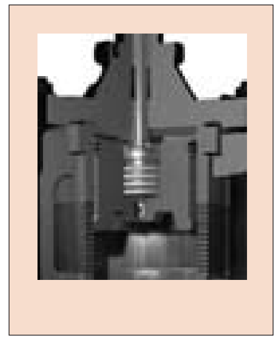


Figure 3: Example of Spring-type Pilot Balanced Valve Plug

Tight shutoff

Shutoff is a critical component to valve performance, especially in applications that dump to the condenser. If the bypass valve leaks, costly steam is lost to the condenser. Recent experiences have shown that a leaking bypass valve can have at least a one to two megawatt impact on the performance of a power plant. The ability to achieve and maintain tight shutoff (ANSI Class V or better) is one of the most critical aspects of turbine bypass valves today. The most prevalent technology used in the past to achieve tight shutoff relied upon a pilot balanced valve plug. This construction utilizes a smaller orifice inside of the main valve plug that is intended to act as a balanced plug during normal operation and an unbalanced plug during shutoff conditions to maximize valve seating force. While the pilot balanced trims do provide a great deal of seating force when in the shut position, ensuring that this occurs after repeated operation is a concern. In order to provide stable control during operation, the inner pilot plug must remain in the open position. This is normally accomplished by using a spring to hold the pilot plug in place (See Figure 3). Over time, the spring can relax, which will cause the inner plug to not be fully engaged when in the shut position. One way that this effect is overcome is to eliminate the springs holding the inner plug in place. While this eliminates the issues with spring relaxation, it can introduce a fair amount of hysterisis into the system and can cause the valve to go unstable under certain operating conditions. In order to maintain the best long term shutoff, it is key to provide adequate sealing while minimizing total overall actuator force for the best installed cost. The latest technology utilizes a fully balanced valve plug for stable operation while providing the sealing between the plug and cage. Instead of relying upon piloted trim that requires repeated maintenance and

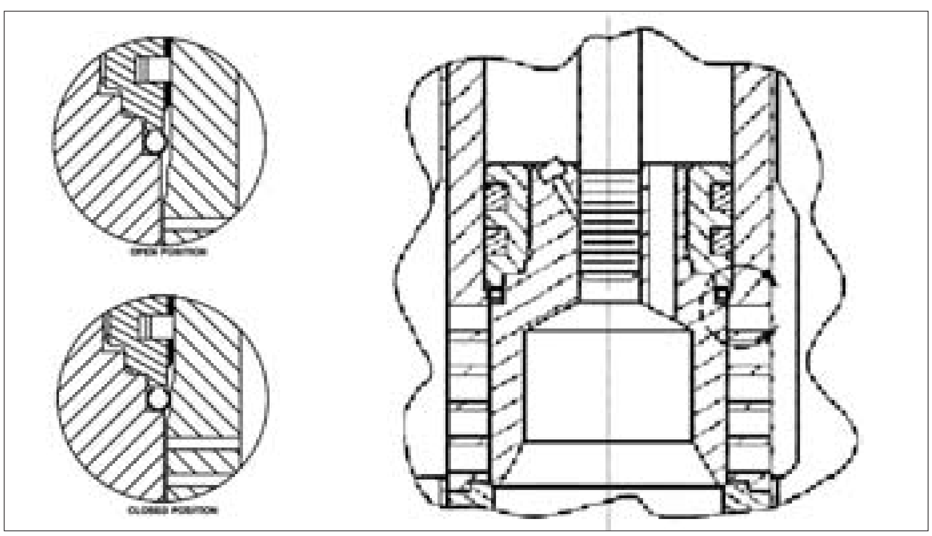


Figure 4: Cross Section of Balanced Trim with Tight Shutoff

tuning, this design obtains shutoff by utilizing a pressure-assisted seal between the plug and cage. By sealing in this manner, touch up to the seat and plug surfaces can be done without affecting shutoff life. Figure 4 shows a cross section of a truly balanced valve plug that can achieve Class V shutoff and beyond.

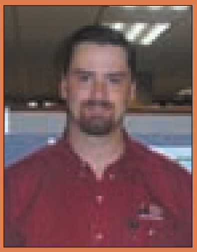
Controllability and stroking speed

The selection of the valve is the first step in providing the optimal steam conditioning solution. Another major step is the proper selection of the actuator and accessories. Specific attention needs to be paid to the stroking speed requirements, failure position, accurate step response and overall reliability of the package. The basic operation of a bypass valve calls for fast opening speeds under steam turbine trip conditions. This does not necessary mean that a fast stroke speed up to 100% open is required, but rather a positioner that provides the required amount of bypass flow. At startup, the valves need to be able to throttle accurately, but not at the speed necessary during a turbine trip. Typical actuators for turbine bypass valves include pneumatic and electro-hydraulic piston cylinders. Advances in pneumatic technology allow a user to have a more cost-effective option that still provides the required performance.

Stroking speed is typically gained by using volume boosters to amplify the supply air to the actuator to obtain quick results. However, stroking fast is one thing. Being able to provide tight control on large step responses is another. In order to provide the best control and minimize the need for repeated tuning in the field. The accessory package must be properly selected. The use of quick exhaust valves has been used for many years, but requires repeated tuning as the internals of the device degrade. If not caught in time, performance of the valve assembly can be jeopardized. Along with the proper actuator accessories, the valve positioner must be able to allow for online monitoring of these critical valves. Online monitoring allows the user to identify potential issues before they occur and cause the plant to trip offline. This will also identify only the valves that need servicing during a scheduled outage and minimize the unnecessary tear down and inspection of adequately performing valves.

Summary

After discussing the multitude of critical issues, it is no wonder the turbine bypass valves are the most critical valves to the performance of a power plant. Selection of the latest technologies ensures that the user will receive that latest in noise abatement, minimized straight pipe requirements, shutoff and overall performance. ■



About the author

John Wilson is a Severe Service Sales Engineer with Fisher Controls International in Marshalltown Iowa, USA and carries a B.S. in Chemical Engineering from the University of Nebraska. For the past years, he has worked extensively on severe service applications focused on the power industry. Prior to joining Fisher Controls, Mr. Wilson worked for the Omaha Public Power District and the Nebraska Boiler Company.