Upgrade of a Flowserve-Anchor/Darling Globe Valve

The procedure involved in upgrading a leaking core spray test bypass valve and the reasons why this valve developed problems were discussed in a paper presented at the 2008 Motor Operated Valve Users Group held in Orlando, Florida in January 2008.

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Background

The core spray (CS) system is one of four emergency core cooling systems (ECCS) installed on General Electric (GE), boiling-water-reactor (BWR) design nuclear power plants. The CS system operates either independently or in combination with other systems to limit the temperature of the fuel bundle cladding to 2200˚F during possible pipe break conditions in the nuclear system process barrier. Its operation ensures that the fuel core remains covered with coolant (high pressure water) during and following design basis events such as a loss of coolant accident (LOCA).

Each core spray system loop consists of one, 100% capacity, motor driven, centrifugal pump; one core spray sparger and associated valves, piping and instrumentation. The pumps are designed for high volume, low pressure operation. Each core spray pump takes suction through a strainer in the suppression pool and discharges to the core via the core spray sparger for that loop.

The core spray test return valves provide BWR plants the opportunity to test their core spray system while on-line. To accomplish this a test bypass line is utilized which directs flow from the core spray pump discharge away from the reactor core and back to the suppression pool (i.e. Torus). The suppression pool is part of the reactor primary containment system and is designed to be a heat sink for reactor coolant released into the primary containment. The CS bypass valve installed within the test bypass line is the core spray test return valve. This valve provides the necessary backpressure to test the core spray pump against full load conditions.

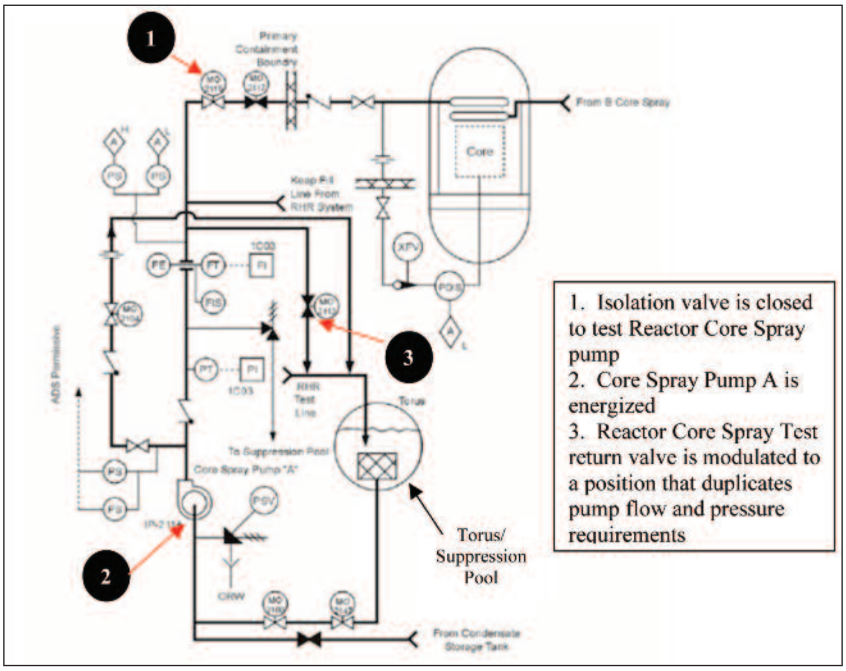


Figure 1: Core Spray System Simplified Diagram

Should the plant receive an actual core spray signal during testing, the CS test isolation valves will automatically close which removes the bypass line from the flow path (see Figure 1).

Original Construction

FPL Energy-Duane Arnold Energy Center (DAEC) nuclear plant was originally built with 2, 8", class 300, carbon steel Anchor/Darling globe valves actuated by Limitorque SMB-1 electric motor operators as their core spray test return valves. These original construction globe valves contained quick opening trim and no cavitation protection as specified on the original valve specification sheet. It is well known that many first generation system designers considered standard line size globe valves to be excellent throttling devices for reactor core spray systems however, in practice, this has seldom held true. Plant operators usually find that the valves demonstrate the presence of a significant amount of vibration and cavitation when the valves are used for high pressure drop throttling. Not only does this damage the valves but it can also damage other piping components such as pipe supports, instrumentation connections, pump and heat exchanger nozzles and pipe welds due to vibration. In fact, Duane Arnold engineers had to replace the CS test bypass valve downstream piping due to wall thinning as a consequence of this cavitation damage.

In order to perform the core spray test with pump discharge diverted to the suppression pool, the A/D test return valve had to be opened only a fraction of an inch due to the quick opening trim supplied on the original valve. The combination of minimal opening height of the valve and full pressure pump discharge diverted to the suppression pool at near atmospheric pressure condition resulted in the valve experiencing erosion, high fluid flow velocities and significant cavitation.

Cavitation

In valves similar to and including the existing Anchor-Darling globe valve, the actual control of fluid occurs when the area of the cylinder between the open plug and seat ring is equal to or less than the area of the seat ring bore. The original A/D core spray test return valve reached full capacity or Cv of 730 at 1.875" of stroke. Because this was a quick-open characterized plug, the valve was very nearly in full flow at 1.25" or 67% of stroke. To control the required flow or Cv for the core spray system test, the valve plug had to be positioned less than 1/4" from the seat which equates to a Cv value of approximately 155. To compound the difficulty in maintaining such a small opening height, these valves are manually modulated from the control room via the Limitorque motor operator which is difficult to control when making 0.100" adjustments to the opening height of a valve. Either a linear or equal percent characterized plug would have resulted in a significant improvement in opening height amount and control although it would have no effect on preventing cavitation.
Cavitation was induced by the large pressure drop that this valve experienced. The reactor core spray pump discharges at a nominal pressure of 264 psi. The diversion of the pump discharge to the suppression pool at atmospheric pressure resulted in the full operating pressure also becoming the pressure drop experienced by the valve, the lowest pressure point occurring just past the seat/plug interface at the vena contracta. The value of this low pressure point was lower than the vapor pressure of the reactor core spray water. This allowed vapor bubbles to form in the flow stream as it passed through the valves. In other words, the water tried to boil at the seat and plug interface. As the fluid passed downstream of the seat, the fluid pressure increased to a value above the vapor pressure. This resulted in a violent implosion of the vapor bubbles as the bubbles were forced to condense. When vapor bubbles implode near a surface such as the inside of a valve body, pressure spikes as high as 100,000 psi are possible. Referring to figure 2, a vapor bubble forms when the pressure of the fluid drops to a level below the vapor pressure. This occurs in throttling globe valves at the plug seat interface where velocities are highest and pressure is the lowest. After the plug seat interface, the fluid enters the downstream portion of the valve body where the flow area greatly increases. This increase in flow area acts to significantly slow the velocity of the fluid and allows the pressure to recover. If the pressure recovers to a value above the vapor pressure, cavitation is experienced. If the pressure does not recover to a value above the vapor pressure, flashing is experienced. When a valve is cavitating, any bubbles formed in the seat area will collapse violently downstream. This violent collapse causes the loud rattling sound often heard in a cavitating valve. If the collapse occurs next to a surface, such as the belly of a globe valve body or the face of the valve plug, an unbalanced force will exist perpendicular to the surface. This unbalanced force is capable of the 100,000 psi spike which, at a minimum, will erode the passive layer of the surface. The host material sacrifices metal to reform the passive layer which is again destroyed by the cavitating media. Over time, the repeated destruction of the passive layer results in pitting and material loss. The loss can be so drastic that the valve body is in jeopardy of losing its pressure boundary integrity.
To further compound the problems experienced at Duane Arnold, the fluid passed through the plug and seat area at its highest velocity (200 ft/sec). This is up to 140 mph wearing away at the valve internal surfaces. This velocity is much faster than any recommended flow for continuous or intermittent duty. The excessive velocity resulted in erosion of the valve seat and plug in addition to the damage caused by cavitation.

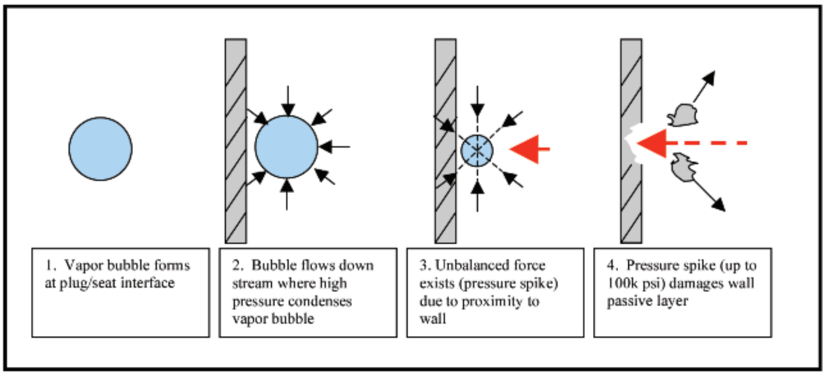


Figure 2: How pitting may be caused by vapor bubbles

Valve Performance History

Beginning in 2003, Duane Arnold began to suspect excessive looseness of the valve disc and guide during test flow conditions by way of excessive vibration and noise from their core spray test bypass valve. On June 19, 2003 a work order was authorized to perform an internal inspection of MO 2112, core spray loop A test bypass valve during the next refueling outage. In the meantime, deterioration of the packing was captured during normal, routine walkdowns of the system. Leaks as small as 60 drops per minute became as large as 350 drops per minute by March 2004.
In April 2005, during the scheduled refueling outage (RFO 19), Duane Arnold engineers performed an internal inspection of their core spray test return valve per the requirements of their original work order. Inspection revealed that the valve body was seriously eroded in the area of the seat ring as well as the disc guide/skirt. The tack weld from the stem nut to the disc had also cracked, all symptoms of erosion and cavitation. Duane Arnold chose to replace the stems and discs on the spot with complete valve replacement scheduled for their next refuel outage in March 2007.
The conclusion was that the velocities across the opening between the plug and seat ring were so high due to the flow required that the induced turbulence caused the plug and piping to vibrate. The

high velocity liquid had quickly eroded the valve internals as well. This velocity was present in the valve where the fluid flows through the area between the plug and seat ring at the test conditions.

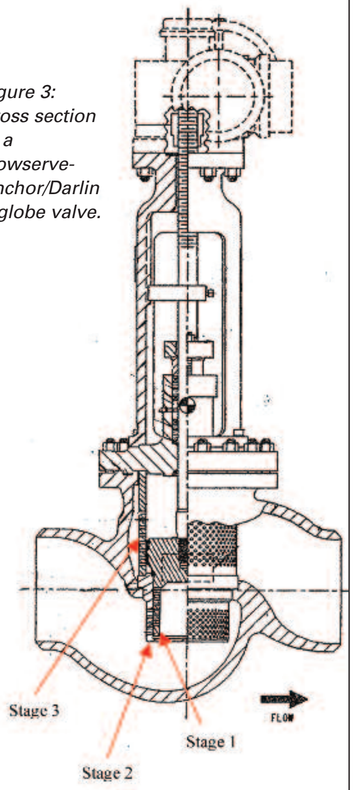
Replacement Valve

Duane Arnold engineers contacted Flowserve for a replacement valve. Their criteria mandated a valve in equal size and class except made from 316 stainless steel. It also had to accept existing actuation, a Flowserve-Limitorque SMB-1. Flowserve engineers were able to meet this requirement with a new version of the Anchor Darling valve complete with friction element trim and a characterized plug. In addition, by matching the original valve weight, a Torus Attached Piping (TAP) seismic stress analysis was not required for this valve replacement saving a significant amount of money for FPL Energy-Duane Arnold.

Flowserve first addressed the low opening height of the original valve (<.250") by supplying a linear profile trim in lieu of a quick opening trim. With a linear profile trim, a 25% open valve will produce 25% total valve Cv capacity; a 50% open valve will produce 50% total valve Cv capacity and so on. Linear profile trims are recommended for applications where the valve represents a major portion of the total system differential pressure. In this application, the valve represents the total system pressure drop with the exception of the inherent pipe friction losses. The linear trim was obviously the best choice as the valve now reaches full flow capacity when open at a manageable 80% full stroke position.

To address the cavitation problem, the Flowserve solution utilized 3 stages of anti-cavitation trim. The unique design employs a flow-under-seat flow path with the first stage of the friction element fixed to the bottom of the valve seat. Flow is forced laterally through the small holes in the trim thus preventing direct impingement of the flow onto the valve plug or body walls. Additionally, the flow impinges upon itself thus significantly reducing the pressure without relying on mechanical friction. The second stage of trim, attached to the bottom of the plug, forces the flow to change directions 180˚ from the entry direction again causing

Figure 3: Cross section of a Flowserve-Anchor/Darling globe valve.



another pressure reduction of the media. With the first two stages of trim arranged inside each other, the Flowserve-Anchor/Darling valve is imposing the maximum amount of flow element friction during the lowest opening heights of the valve, precisely where it needs to occur to control damage due to the high pressure drop and high fluid velocities. It also results in a compact package which allows the use of a same sized valve as the original construction. After the second stage of trim, the flow continues in the same direction through the third stage of trim. The second and third stages of trim are separated to allow an area of sudden expansion of the fluid which produces another stage of pressure reduction. By the exit of the third stage, all the pressure drop has occurred within stages 1 and 2 or between stages 2 and 3. By taking smaller pressure drops through each stage Flowserve has prevented the fluid pressure from ever dropping below its vapor pressure. This ensures that cavitation cannot occur. The valve internals and all downstream components are protected from damaging cavitation.

Post-Upgrade

Duane Arnold system engineers have been very pleased with the upgrade. Verbatim comments include: "The flow control with the valves is superior making the STP (Surveillance Test) much easier to perform. I applaud this modification."

By thorough analysis of the system conditions and by listening to the issues imposed on DAEC system engineers, Flowserve was able to offer a robust, cost saving solution that will meet the long terms needs for safe, reliable power generation.

About the authors

Thomas M. Beaulieu (on left) obtained a BSME at the University of Maine, an MBA from Elon University in North Carolina and is a Registered Professional Engineer. He has, for the last three years, held the post of Product Manager for high pressure gate, globe and check valves at Flowserve in Raleigh, North Carolina. Prior to this Mr Beaulieu has worked as Engineering Manager, Design Engineer, QA Manager and Field Service Engineer for various companies. He has had thirteen years experience with valves and 7 years experience with nuclear utilities.

Paul Collingsworth (on right) joined Duane Arnold Energy Center (now owned by FPL Energy) in 1983. His current role is Senior System Engineer since 1997.

His qualifications include a BS in Mechanical Engineering from Purdue University (1980), Senior Reactor Operator's Licence from the NRC (1985) and ANSI 45.2 Lead Auditor Certification. He is also a Chairman of the BWR Owners Group subcommittee for low pressure emergency core cooling systems, a member of the BWROG Advisory Council and EPRI Serve Water subcommittee. Mr Collingsworth has received two Top Industry Practice awards for turbine inspection and river improvement projects.