We Solve Control Valve Problems®

BWR Control Rod Drive Pump Flow Control Valves

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Abstract

Since they were put in service, the Control Rod Drive Pump Flow Control Valves at Perry Nuclear Station have required excessive maintenance and encountered performance problems. These pneumatically operated globe valves are required to continually throttle fluid at a high pressure differential and be available for increased flow requirements when the system demands it. The previously supplied valve was equipped with a limit closing stop to ensure that a minimum flow was maintained. Severe cavitation damage to the trim required the plant to make continual travel-stop adjustments.

Perry's solution was to purchase CCI DRAG® control valves with a unique fixed minimum flow design and technology that eliminated all cavitation. The valve has been installed for year and a half and is currently operating without any problems.

System

The Control Rod Drive (CRD) charging water pump discharge is used to supply high pressure water (approximately 1800 psig) to the system. The subject valves are used to throttle flow to approximately 60 gpm. During plant power operation the reactor is at approximately 1000 psig and the pressure drop across the subject valves is near 800 psid. However, during refueling operations, the reactor is open and the pressure drop across the valve increases to very near the full 1800 psid.

Previously, installed valves are globe style with a single stage drilled hole cage, made from SA 564 TP 630 hardened martensitic stainless steel. These valves have the minimum flow provision to ensure cooling water to the control rod drive mechanisms is not interrupted.

These valves had extensive cavitation and velocity induced erosion damage and required periodic changes to their limit stop position to compensate for trim erosion.

Figure 1: Cavitation and high velocity erosion of cage

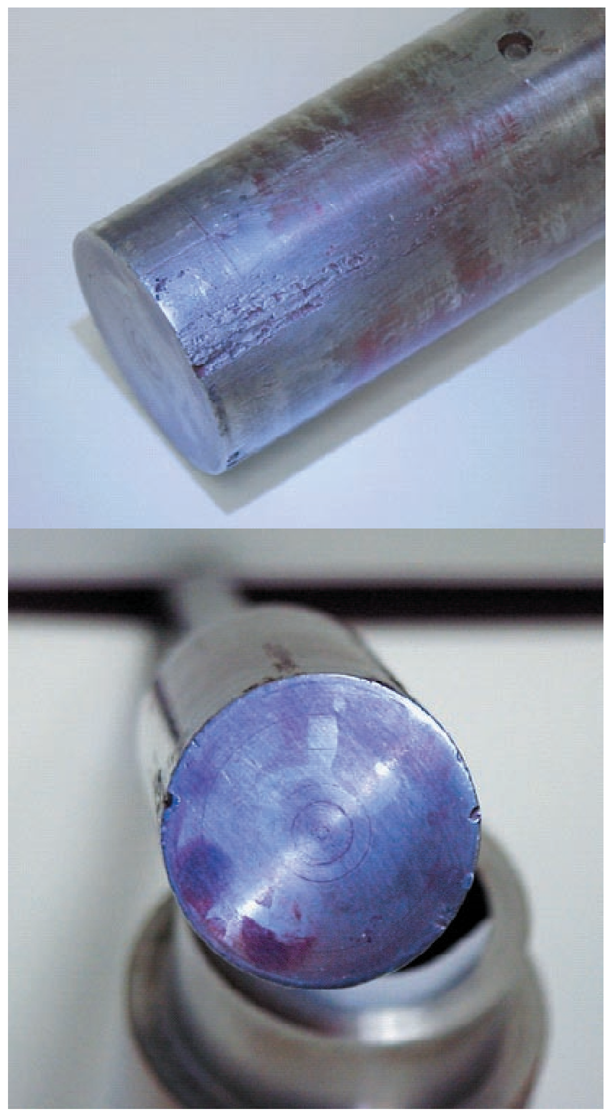

Figure 2: Cavitation and high velocity erosion of plug

Table 1: Service Conditions

Fluid	Water/Steam				
Critical Pressure	psi G	3194			
Critical Temperature	deg F	705.5			
Condition		Case 1	Case 2	Case 3	MIN FLOW
Fluid State		Water	Water	Water	Water
Liquid Vol Flow Rate	gpm(US)	80.0	68.0	50.0	35.0
Inlet Pressure	psi G	1685.0	1685.0	1685.0	1850.0
Outlet Pressure	psi G	1320.0	1320.0	1320.0	260.0
Pressure Differential	psi	365.0	365.0	365.0	1590.0
Inlet Temperature	deg F	140.0	140.0	140.0	140.0
Density	lbm/ft3	61.69	61.69	61.69	61.72
Vapor Pressure	psi G	-11.8	-11.8	-11.8	-11.8
Viscosity	cpoise	0.4691	0.4691	0.4691	0.4694
Service Cavitation Index	$\sigma_1 = \frac{P_1 - P_V}{P_1 - P_2}$	4.65	4.65	4.65	1.17
Required Flow Capacity	Cv	4.206	3.575	2.629	0.8819
Previous Valve trim exit velocity	ft/sec	191	191	191	399

Perry contacted the OEM and other valve companies for a long term solution to this problem.

The initial analysis was to take a look at the service conditions and see if it provides information on the probable causes for valve damage.

In the above service conditions, the trim exit velocity for the "min case" is ≈ 400 ft/sec! The Cavitation Index is 4.65 for three of the cases and 1.17 for the third case where the valve is open most of the time.

This helped predict that the process conditions were resulting in cavitation damage and high velocity erosion. Note: the Cavitation Index is not scaled for pressure or size. The conclusion was excessive trim exit velocity to be the root cause of vibration and cavitation.

Solution

Any solution must meet the following criteria:

1. Solution must be proven by cavitation test
2. Cv must be verified
3. Solution must be robust and reliable, provide long-term permanent fix to velocity induced erosion problem

For long term, the selected solution was to replace the existing valve with a new design which must be designed to reduce pressure in stages, and as a result limit the velocity of the fluid in the trim (Figure 3) so that the pressure never falls below the fluids' vapor pressure.

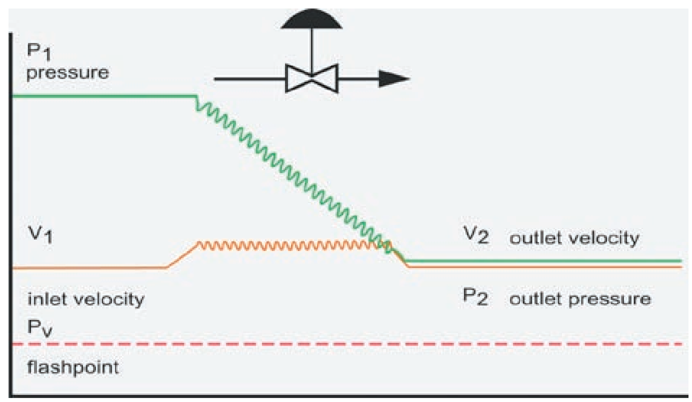

Figure 3: Flow path in a multi-path multi-stage trim

By using multiple right angle tortuous flow paths (Figure 4), it is possible to reduce the trim velocity to acceptable levels. The selected velocity limit to reduce the potential for vibration and cavitation was 100 ft/sec per ISA recommendations (Reference 1).

Each individual flow path has a series of turns that breaks up the pressure drop across the valve into multiple stages, and has expanding passages to reduce fluid exit velocity.

This approach uses a series of flat metal disks to form a trim assembly. Each disk has a flow pattern of successive right angle turns cut into its flat surface. When stacked, these pathways can be matched or mismatched between individual disks to create a labyrinth flow pattern that enables trim to be infinitely tuned to control flow in a manner that maintains positive operating characteristics throughout the valves' operating range (Figure 4). The flow path for each disk is opened as the plug moves within the center opening of the disk stack.

This flow method controls the damaging effects of velocity in two ways; by dividing the flow into many small streams of low mass flow rate, and by forcing fluid through a series of sharp right angle turns to affect the pressure drop steps. The energy in the fluid flow will be sufficiently controlled so that cavitation and vibration are eliminated.

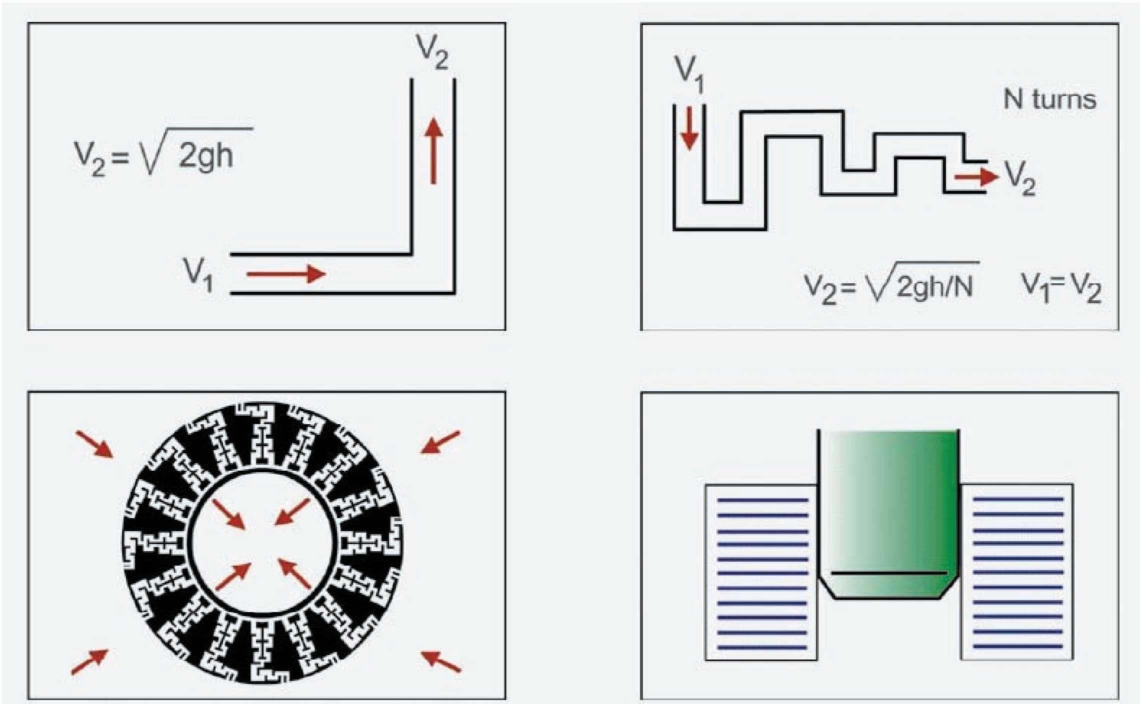

Figure 4: Multi-Stage Multi-Path Flow Geometry

CCI provided a multi-stage multi-path disk stack, with required number of stages to reduce the damaging velocity to lower levels. The maximum trim velocity was reduced to less than 51 ft/sec which is eight times lower than what existed.

Table 2: Service Conditions with New Trim

Fluid	Water/Steam					
Critical Pressure	psi G	3194				
Critical Temperature	deg F	705.5				
Condition		Case 1	Case 2	Case 3	MIN FLOW
Fluid State		Water	Water	Water	Water
Liquid Vol Flow Rate	gpm(US)	80.0	68.0	50.0	35.0
Inlet Pressure	psi G	1685.0	1685.0	1685.0	1850.0
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Vapor Pressure	psi G	-11.8	-11.8	-11.8	-11.8
Viscosity	cpoise	0.4691	0.4691	0.4691	0.4694
Service Cavitation Index	$\sigma_1 = \frac{P_1 - P_V}{P_1 - P_2}$	4.65	4.65	4.65	1.17
Required Flow Capacity	Cv	4.206	3.575	2.629	0.8819
Stages Provided	Stages	12	12	12	16
New Valve trim exit velocity	ft/sec	34	34	34	51

Table 3: Cavitation Test Data

Inlet Pressure (psig)	Outlet Pressure (psig)	Flow Rate (gpm)	Cv	Stages, 90 deg Turns	Trim Exit Velocity ft/sec	Vibration, g's	Crackling Noise
1930	246	35	0.85	16	53	0.06	No
1925	255	79	1.94	8	103	0.11	No
1690	1305	79	4.04	2	108	0.13	No
1735	35	78	1.90	8	104	0.17	No
1735	1320	35	1.72	8	51	0.07	No

Cavitation Test

CCI had performed a high pressure drop cavitation test in the past specifically for CRD control valves (Figure 5). The test simulated all five service conditions with additional pressure drop margin than what the valves were expected to perform with steady state conditions. Each condition was held for at least 15 minutes. The temperature of the fluid was at 65 oF, which was lower than the actual service condition temperature. An accelerometer was placed on the downstream pipe to measure vibration and also aural detection of cavitation was accomplished by listening for crackling noises. The trim parts finish was inspected pre and post test to look for cavitation pits.

The testing demonstrated that the valve was capable of handling the service conditions at the Perry Station. The trim exit velocities are higher in the tested valve than was expected in the actual plant conditions. Post inspection of the parts did not show any cavitation pits on the trim parts.

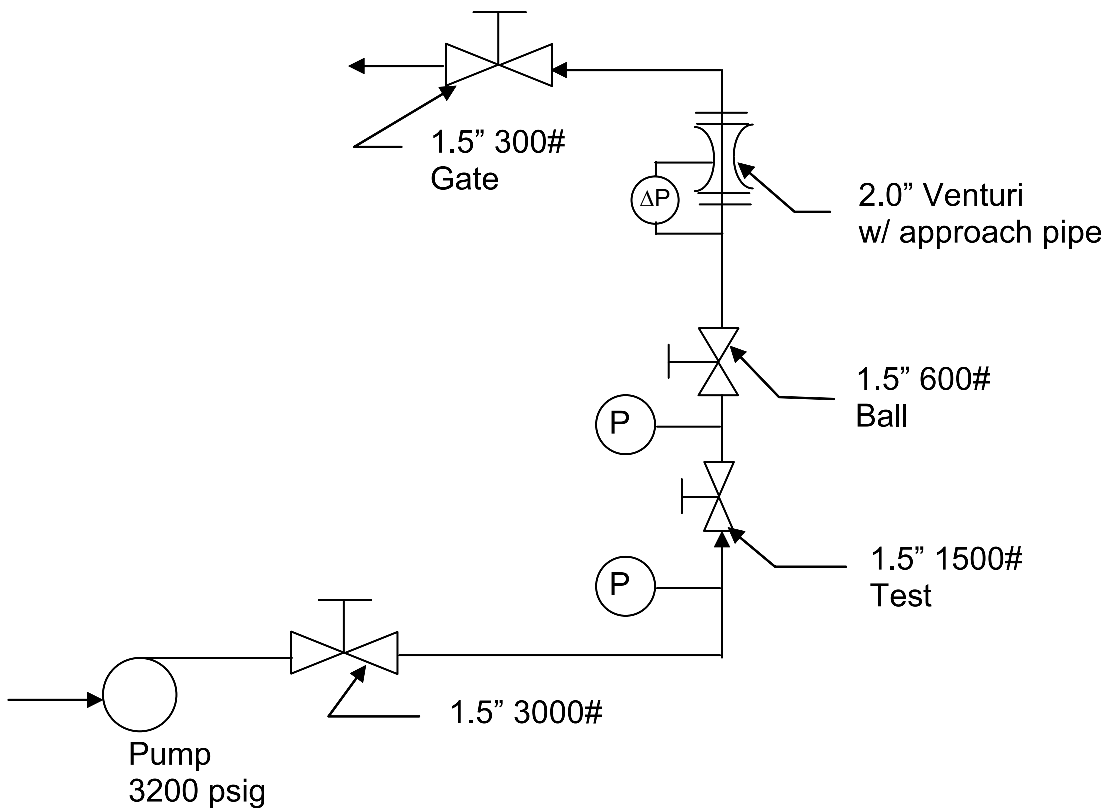

Figure 5: High Pressure Cavitation Test Loop

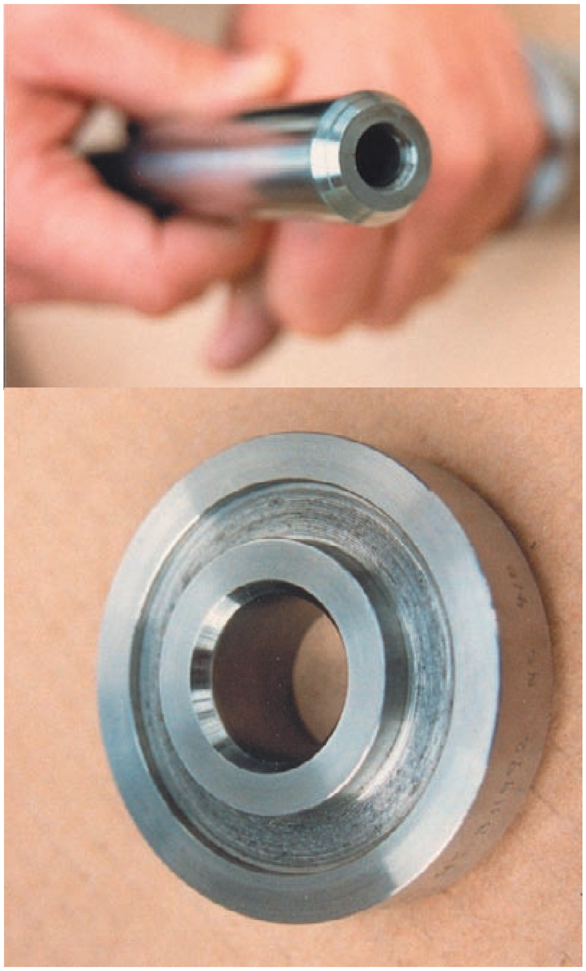

Figure 6: Post Test Spindle and Seat Ring showing no cavitation damage

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Plant Installation and Performance

Since installation at the Perry Station over 18 months ago there has been dramatic improvement in the system performance. The valves were installed early in their last refueling outage and placed into service during the remainder of the outage. The first indication that the valves were indeed an improvement was the silence in the area surrounding them. Individuals familiar with the Plant were skeptical that the CRD system was in service because they were accustomed to the deafening roar that issued from the previous valves. The valves have provided exceptional service since their installation.

The valves previously used in this application had suffered significant erosion damage to their trim and even their bodies. The valves required rework every other refuel outage to correct their condition. The CCI DRAG® valves are expected to completely eliminate the need to rework the valves. Use of CCI DRAG® valve design is being pursued for other plant applications requiring resistance to damage from flow control at high pressure drops.

References

(1) Control Valves – Practical Guides for Measurement and Control" edited by Guy Borden, Jr. and Paul G. Friedman, 1998 edition published by ISA.