Severe water hammer damage caused by swing check valve closure characteristics following main feed pump trips has resulted in the approval of plant modifications to install a more suitable check valve design. During the 1970's and 1980's, more than 350 large bore swing check valves in main feed pump discharge applications at Electricité de France (EdF) nuclear plants were replaced with Model DRV-B and Model DRV-G NozzleCheck valves. The NozzleCheck effectively eliminated pressure surge problems without adding additional maintenance burden associated with damping systems and soft seat designs.

Successful use of NozzleCheck valves in EdF nuclear plants: Paving the way for US applications

By Rob Gormley, Enertech, Curtiss-Wright Flow Control Corporation, USA

The success in EdF plants broke down significant barriers to new product introduction into the US nuclear industry. Replacing a poor performing valve with an alternate design requires not only a rigorous engineering review of design adequacy, but also a demonstrated history of performance in similar applications at other nuclear plants. In the early 1990's, the first NozzleCheck valves were installed in US nuclear plants taking advantage of the success achieved in European nuclear plants. The Calvert Cliffs Nuclear Plant in Maryland replaced 24" ASME/ANSI Class 150 Swing Checks with Model DRV-G NozzleCheck valves and the FitzPatrick Nuclear Plant in New York replaced 18" ASME/ANSI Class 900 swing checks with Model DRV-B NozzleCheck valves.

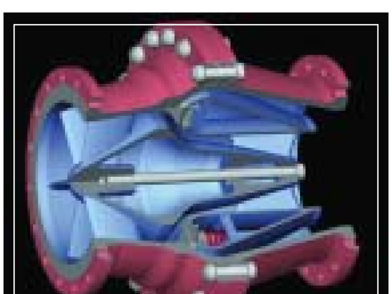

Figure 1: Model DRV-G NozzleCheck

The most difficult hurdle to overcome when introducing a new valve design into the nuclear industry is getting the first one installed. However, it is not enough to just have a valve installed; the valve must successfully perform under the high profile scrutiny of disassembly/inspect, non-intrusive diagnostics (NIT), and in-service testing (IST) programs over an extended period of time before it can be recognized as acceptable for use in critical nuclear applications. After thirty years of experience in the most challenging applications, the NozzleCheck has become an accepted solution to check valve performance problems related to premature wear, water hammer and leakage during low pressure testing.

NozzleCheck design and performance characteristics

The Model DRV-G in figure 1 was the first NozzleCheck model developed and patented by Mannesmann Demag Meer of Mönchengladbach Germany in 1935. See figure 2. The Model DRV-G has a two-piece cast body connected via a center flange. Flow through the Model DRV-G takes

Figure 2: NozzleCheck installed in French nuclear power plant

two paths, one through the inside of the disc's annular area and another around the outside of the disc between the body and diffuser. The geometric profile of the disc, diffuser, and body combine to create a low pressure area downstream of the disc; this area is gradually expanded minimizing pressure loss and flow separation.

The Model DRV-B in figure 3 is very similar to the Model DRV-G with the exception of the center flange; it has a one-piece body with similar internals. Until the late 1990's, the Model DRV-B's use was restricted, due to its low Cv, to applications that could tolerate a higher pressure drop than a swing check. The Model DRV-B was >>

redesigned to include changes to the profile of the body and diffuser, reducing the Model DRV-B's K-factor (or resistance to flow) from 1.5 to 0.8, making it comparable to the Model DRV-G. The redesign effort also reduced the face-to-face dimension, weight and cost of the valve, making it a more cost-effective option when replacing swing check, tilting disc or dual plate check valves valves.

Model	Approximate K Factor (varies slightly with size pressure class)
DRV-G	0.82
DRV-B	1.5
Re-Designed DRV-B	0.80

To convert K to the more commonly used C_V term:

$$C_V = \sqrt{\frac{891d^4}{K}}$$

d = internal diameter of pipe in inches

Pressure Drop across the valve can be approximated using:

$$\Delta P = \left(\frac{Q}{C_V}\right)^2 \frac{\rho}{62.4}$$

Q = Flow in gallons per minute

ρ = fluid density in lb/ft^3

Characteristics of the Model DRV-G and Model DRV-B include:

Figure 3: Model DRV-B NozzleCheck

1. Low mass disc compared to the same size and pressure class swing check.
2. Axial disc movement with very short stroke from the closed to the fully open position and vice versa.
3. Helical springs contained within the diffuser that apply a closing force to the disc to decrease closing time and provide additional seating force in low differential pressure applications.
4. Unique internal geometry that creates a low-pressure area immediately downstream of the disc and gradually expands to recover pressure loss.

These characteristics combine to provide a check valve that closes rapidly in response to flow reversal. While it is generally assumed that a fast closing check valve causes a slam resulting in the generation of a pressure wave, this is not necessarily true. The key variable in determining the magnitude of pressure wave generation is the velocity through the check valve at the instant of closure.
Swing check valves close quickly but don't start to close until significant reverse flow is going through the check valve. See figure 4. In comparison, a NozzleCheck reacts very quickly to flow direction changes and closes at nearly the zero velocity position eliminating damaging pressure surge. The closing time of a NozzleCheck can be matched to the specific application requirements by custom designing the spring for the transient condition.
Dynamic Response is the term used to describe a check valve's response to flow deceleration and is

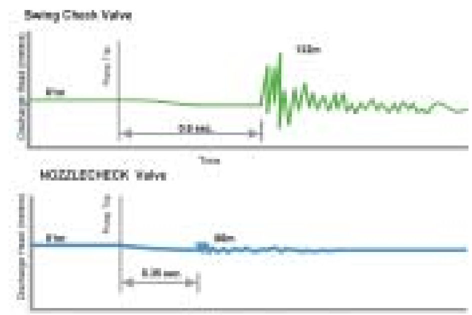

Figure 4: Swing check valve vs.Nozzle-Check valve

usually illustrated via a system deceleration vs. reverse velocity curve. Extensive dynamic testing has been performed on the various models of NozzleCheck valves to generate accurate dynamic performance curves that are essential for spring sizing and prediction of transient response. An example is included; see figure 5.
In addition to improved dynamic response compared to a swing check, a NozzleCheck will attain the fully open position at a much lower velocity. A NozzleCheck with a weak spring will fully open at approximately 3 feet per second (assuming ambient temperature water), a strong spring will require 8 feet per second or more if the applications warrants. A velocity of 12-16 Fps is required to fully open a typical swing check valve. A fully open check valve eliminates wear caused by the disc oscillating in mid-position and also minimizes the resistance to flow. The low-pressure area created behind the disc, in addition to the disc shape and position relative to flow, allows the NozzleCheck to attain very low V_{min} values. V_{min} is the characteristic associated with a specific check valve design and defines the minimum velocity necessary to hold the check valve in the fully open position.

NozzleCheck valves in European nuclear plant main feed systems

Due to high pressure, high tempera-

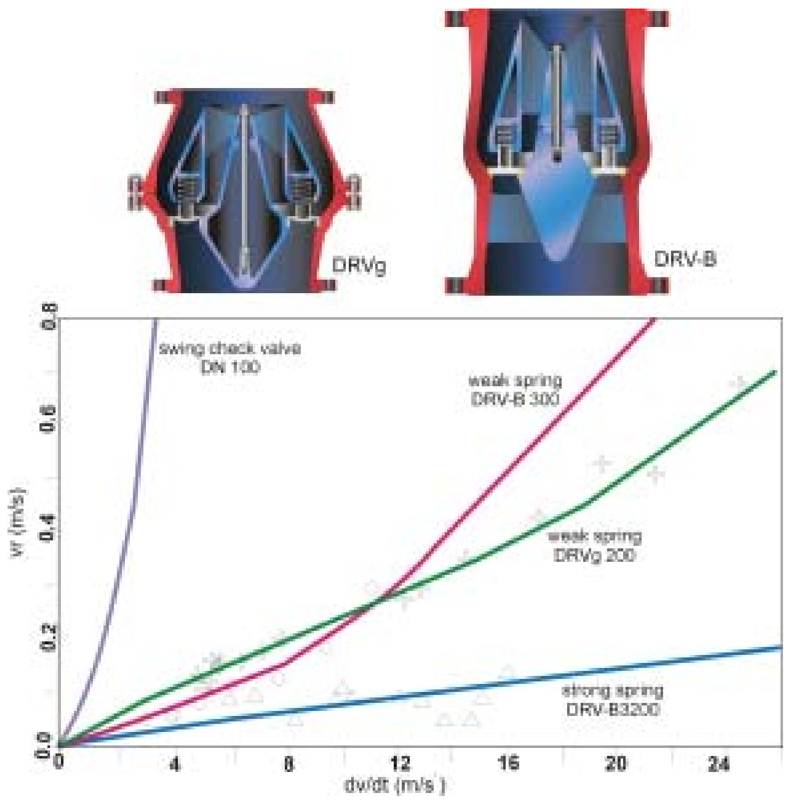

Figure 5: Dynamic Performance Curves

ture and continuous high velocity flow, check valves in typical Pressurized Water Reactor (PWR) and Boiling Water Reactor (BWR), main feed pump flow paths operate in some of the harshest service conditions in a plant. These check valves must provide a high level of assurance that they can close and isolate quickly in the event of a feed header rupture, without damaging upstream or downstream piping. Due to their size and location, it is not economical to perform frequent preventative maintenance on these valves, making a maintenance free design especially important. Feed system check valves and associated damping accessories that require frequent corrective and preventative maintenance are typically one of the most costly valve related maintenance activities during an outage. Damage to main feed headers caused by water hammer, as discussed in detail in A.R.D. Thorley's, *Fluid Transients in Pipeline Systems-2nd Edition*, was the precursor to many of the modifications done to replace swing checks with Model DRV-G NozzleCheck valves. This retrofit resulted in an excess of 350 valves being replaced across the EdF nuclear fleet with large bore, high pressure Model DRV-G Nozzle-Check valves. Water hammer damage and check valve slam were eliminated. Some of the first NozzleCheck valves have had 30 years of operating experience without failures or frequent preventative maintenance being required. Non-intrusive testing is used to validate operability with results indicating no degradation leading to extension of testing/inspection frequency to 20-year intervals in many applications.

Validation of successful application of NozzleCheck valves in US nuclear feed systems

The extensive use of Model DRV-G NozzleCheck valves in the EdF plants paved the way for FitzPatrick to select the NozzleCheck as the solution to premature failures of swing checks in the main feed pump discharge application. A Case Study was presented at the Winter 2004 Nuclear Industry Check Valve (NIC) Conference that provided a detailed discussion of the root cause of the swing check problems, the evaluation of the various options under consideration, the modification process and the review of performance after ten years of operation.

Summary of main feed pump discharge check valve replacement at FitzPatrick

Description of originally installed swing checks:

- Application - feed water pump discharge check valves
- Two 18" ASME/ANSI Class 900 swing check valves (Figure 6)
- Tag numbers – 34FWS- 4A & B
- Inclined seat angle
- Two-piece hanger/disc
- Forged carbon steel body

>>

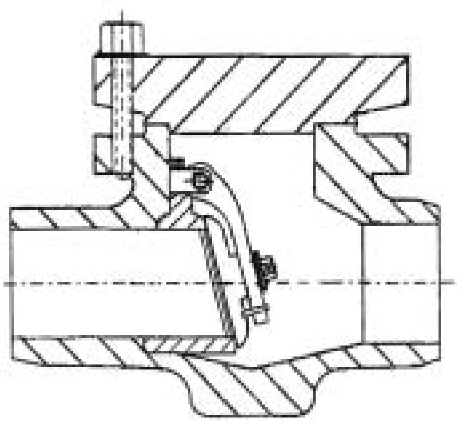

Figure 6: 18" ASME/ANSI Class 900 swing check valve

- Butt weld end connections
- Metal seated
- Commercial grade, ASME/ANSI Class B16.34

Service conditions:

- Maximum design flow – 7,300,000 lb/hr
- Normal flow – 5,277,320 lb/hr (10,544 gpm)
- Minimum flow Rate – 1,980 gpm (startup mode)
- Operating temperature – 373°F
- Operating pressure – 1850 psig
- Horizontal installation
- Both pumps operate at 100% power
- One pump is the lead pump at higher RPM
- Valve inlet is 2.5 diameters downstream from 90°elbow
- Valve inlet is 4.5 diameters from pump discharge
- Both pumps have vertical discharge pipes

Performance review of swing check valves:

- Since startup in 1975, valves failed within an average period of 2 – 5 years.
- Indication of valve degradation, see figure 7, due to seat leakage and pumps spinning backwards.
- Failures include:
  - – complete separation of disc from hanger arm
  - – severe wear of hinge pin
  - – loose bracket bolts and broken welds
  - – valve stuck open due to anti-rotation pin getting stuck under hanger
  - – wear of internals: disc nut, washer and stem
  - – Missing anti-rotation pins

The criteria used to evaluate a replacement valve included:

- Transient hydraulic response
- Steady state hydraulics
- Disc stability
- Size and weight compatibility
- Frequency and ease of preventative maintenance
- Performance history in similar applications
- Vendor support
- Lead time
- Cost

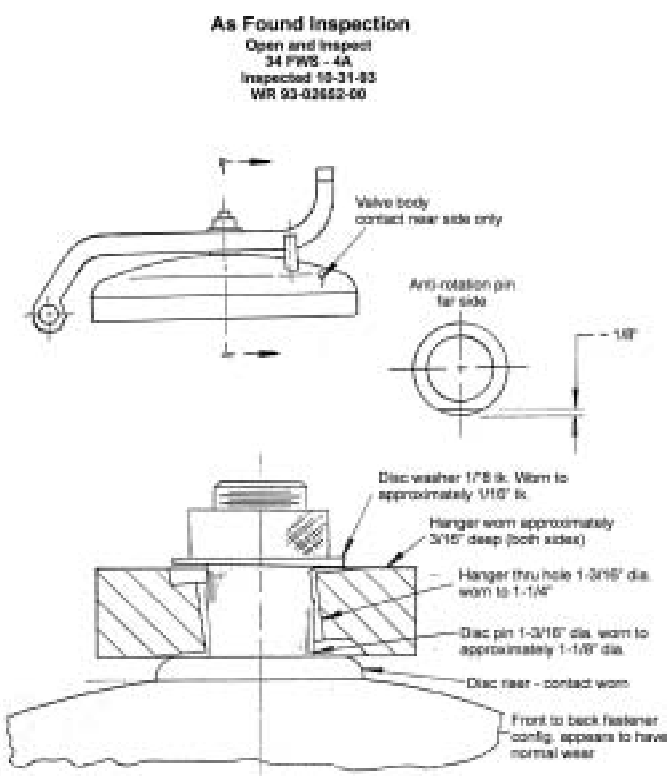

Figure 7: Inspection results of swing check valve

Figure 8: Photo of DRV-B outlet after 10 years of service

The Model DRV-B was evaluated positively in all categories with the extensive experience in EdF feed systems being one of the primary considerations. One of the issues with the Model DRV-B, the older vintage with higher resistance, was its pressure drop compared to the swing check**.** Its resistance to flow was much higher than a swing check with a Cv of 5,000 vs. 8,700, respectively. Since the feed pump is driven by a variable speed turbine, the increase in pressure drop was compensated for by a slight increase in turbine speed. Two Model DRV-B NozzleCheck valves were installed in 1994. A modification was made in 1996 to eliminate wear attributed to the uneven approach velocity caused by the upstream elbows. Since this modification, there has been no evidence of any degradation of internals or loss of seat tightness after 9 years of operation. Figure 8 is an inspection photo from 2004. The valves are currently on an eight-year inspection interval.

Conclusion

The pioneering efforts of EdF to apply NozzleCheck valves in nuclear plant applications has led the way to widespread use of NozzleCheck valves in nuclear plants worldwide. In the US alone, there are over 450 NozzleCheck valves installed in applications where originally installed swing, tilting disc, piston, and dual plate check valves could not provide the necessary degree of reliability without extensive corrective and preventative maintenance. The new Model DRV-B NozzleCheck is being installed in other US nuclear plant main feed applications to replace dual plate and swing check valve designs that have experienced accelerated wear and contributed to pressure surge damage. Enertech, a division of Curtiss-Wright Flow Control, manufactures NozzleCheck valves for nuclear applications worldwide using the original Mannesmann Demag Meer design information. NozzleCheck valves can be manufactured to meet ASME Section III design requirement for safety related applications. The size range of NozzleCheck valves, using four different models, accommodates 1" through 72" applications. The proper application of NozzleCheck valves to solve performance problems requires careful review of service conditions and design requirements. Pressure surge transient problems can be especially difficult to evaluate and may involve multiple variables other than the check valve. NozzleCheck valves provide an alternative to conventional check valve designs and should be considered as a retrofit in operating plants and for new construction projects especially for:

- The discharge of parallel pumps where water hammer is a concern.
- Applications where velocities are not adequate to fully open other types of check valves.
- Containment isolation applications where low pressure gas testing is required. ■

About the author

Rob Gormley is a Senior Product Manager with Enertech, a division of Curtiss-Wright Flow Control Corporation and manages the NozzleCheck product line for the worldwide nuclear market. He holds a Masters Degree in Mechanical Engineering from Stevens Institute of Technology and has 20 years experience working in the naval and commercial nuclear markets in various sales, marketing and engineering related fields. For questions or comments, please email rgormley@curtiss-wright.com.