Flowserve - Edward Valves

Pressure Locking and Over-Pressurization of Double Seated Valves

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Problem

Double seated valves in the closed position with trapped pressure in the bonnet that significantly impedes or prevents opening of the valve.

Solution

Flowserve-Edward has identified multiple solutions to address this phenomena, such as bypass valves and vented upstream seats/discs.

ABSTRACT

Double-seated valves provide benefits over valves with single seats and create few disadvantages. However, field experience reveals that trapped pressure in the center cavity of these valves can be a source of occasional problems. Because actuators are normally sized based primarily on downstream loading, trapped pressure loading on both seats may greatly exceed design limitations and cause the valve to become pressure locked. Trapped pressure may also damage valves if over-pressurization occurs, through heating or freezing of the line fluid. Improvements in packing, bonnet seals, and seats have reduced the means of pressure relief in the center cavity. Fortunately, operating procedures and special design features may be employed to relieve trapped pressure and prevent both pressure locking and over-pressurization.

Introduction

Plug valves, ball valves, and gate valves usually have two seats in series. There are many subtypes of each of these valves, and there is considerable variation in the sealing effectiveness of upstream and downstream seats in different designs. Two seats in series are often thought of as an advantage, and they sometimes provide genuine benefits. When a valve is opened, closed, or throttled with a high differential pressure, upstream and downstream ports provide two orifices in series to reduce the pressure drop across each port (Figure 1). When closed, two seats in series may provide a sealing advantage in the event one of the seats is damaged.

Seat Sealing Effectiveness

Before discussing potential problems with double-seated valves, it may be helpful to consider the forces that influence the effectiveness of the individual seats. Figure 2 illustrates simplified force balances on closed floating ball and gate valves. Note that the differential pressure acting across the closure member (ball or gate) provides a sealing force on the downstream seat at the low pressure side of the valve. Thus, these valves are sometimes referred to as downstream sealing.

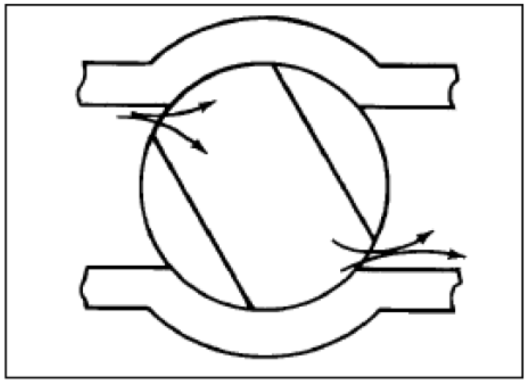

Figure 1: Horizontal cross section of throttled ball valve showing two orifices in series.

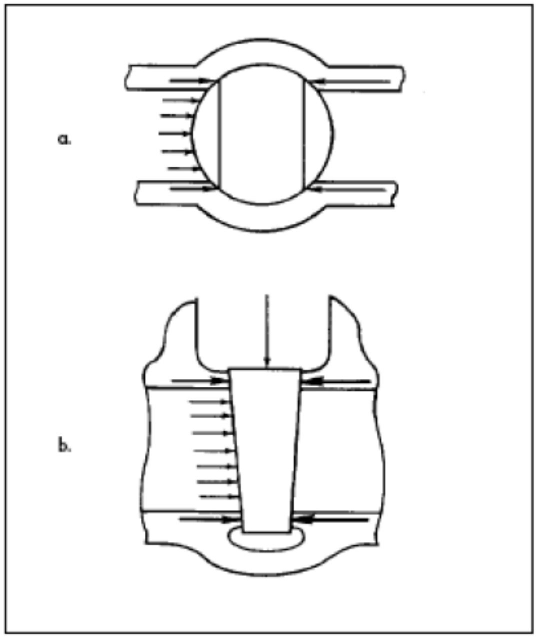

Figure 2: Simplified force balance diagram on closed valves:
a. Floating ball valve
b. Wedge gate valve

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Since the seating forces due to differential pressure may be inadequate to produce effective tight sealing when differential pressure is low, it is common practice to assemble floating ball valves with interference (e.g. controlled “squeeze” on soft seats) which provides some upstream seating force. In wedge gate valves, as illustrated, stem load and wedging produce a loading on upstream seats. Gate valves with parallel seats sometimes employ springs or internal wedges to provide supplemental loading for low pressure sealing. Thus, while all of these valves are normally considered as downstream seating, there is usually moderate to significant loading which provides some sealing effectiveness of upstream seats as well.

The sealing of two seats in series can produce a pressure trapping condition which, in turn, can produce an increase in the force required to open a valve — pressure locking. Heating or freezing of trapped fluid between the two seats may also produce conditions that are hazardous to pressure boundary parts of a valve.

Pressure Trapping

Referring to Figure 3, consider the scenario which accompanies and follows closure of a doubleseated valve. A “flexible wedge” gate valve is shown in the illustration, but other double-seated valves react similarly to one degree or another.

If the valve is closed with a high line pressure and the downstream pressure decreases slowly, the pressure in the valve center cavity, Pc, immediately after closure would be essentially equal to the upstream line pressure.

The behavior of the center cavity pressure after closure depends on many things, such as (1) temperature, (2) type of line fluid, and (3) individual valve design characteristics. For example:

- If the line fluid is either a liquid or gas at ambient temperature (and there is no subsequent temperature change), the pressure Pc would remain constant unless there is seat leakage.
- If the downstream seat leaks to the depressurized side of the valve, the center cavity pressure would decrease, but, since the upstream seat often seals less effectively than the downstream seat, it could “feed” the center cavity to maintain the pressure. Precise prediction of this pressure after closure is impossible, but it would tend to remain near the upstream pressure.
- If the line fluid is at an elevated temperature, the valve would normally tend to cool and approach ambient temperature after closure and cessation of flow. The fluid in the center cavity would tend to contract, reducing Pc. The behavior will be affected significantly by the type of line fluid: – If the fluid is a liquid (e.g. hot water), the pressure would decrease rapidly, possibly approaching a vacuum and producing a vapor cavity. If the upstream seat is not effective at high differential pressure, leakage into the center cavity would tend to offset this pressure decrease in time. Precise prediction of Pc is not possible, but the center cavity would normally be liquid filled after cool-down, with a pressure near the upstream pressure P1. – If the fluid is a as (e.g. hot air), the pressure would tend to decrease slowly in proportion to the absolute temperature. As in the case of closure with a liquid, upstream seat leakage would tend to offset this decrease, and the center cavity would be filled with gas after cool-down at a pressure near P1.

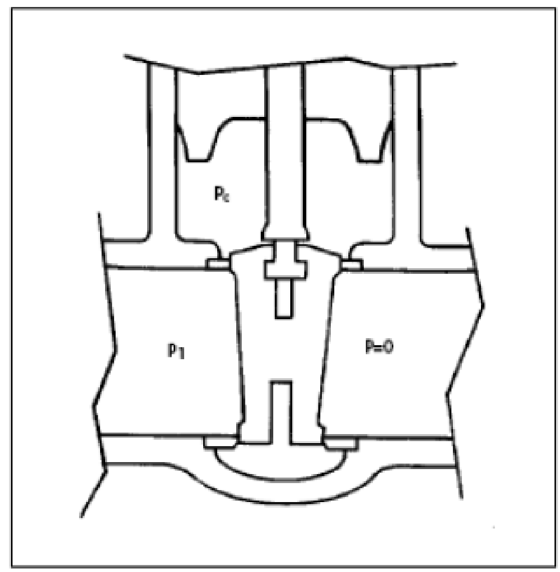

Figure 3: Horizontal cross section of closed flexible wedge gate valve, showing upstream pressure P_1 and center cavity pressure P_C.

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– If the fluid is a condensable vapor (e.g. steam), the process in the center cavity after closure is complicated by condensation when the pressure decreases to the saturation pressure of the trapped line fluid. As in the case of closure with a liquid or gas, upstream seat leakage would tend to offset the decrease in Pc due to cooling, but the incoming leakage would also condense. In the vapor case, prediction of center cavity pressure after cool-down is again impossible, but it would normally be near P1. Significantly, the center cavity would be partially or completely full of condensate (e.g. water), even with a vapor in the upstream line.

To explore the pressure trapping issue further, consider what happens if the system (boiler, chemical process) containing a closed doubleseated valve is shut down, letting P1 go to zero. The fluid left in the center cavity after closure (above) would be trapped indefinitely until relieved by leakage. If a valve in a hot line cools off further after shutdown, pressure may be relieved by contraction of liquid or condensation of vapor, but significant pressure might remain trapped in the valve cavity in some cases; in the case of a gas, the stored energy would remain significant. This could occur with any type of double-seated valve; as shown in Figure 4, both seats in some types of valves can be loaded by the center cavity pressure Pc, thus enhancing seat tightness and increasing probability of longterm pressure trapping.

Since the pressure trapped within double seated valves may not be foreseen, two conditions might present hazards during shutdown if not properly attended to:

1. Leakage from the trapped center cavity might complicate maintenance on nearby equipment. This could be of concern if the trapped fluid is flammable or hazardous in any other way.

2. Opening of the valve during shutdown could cause an unexpected energy release due to relief of trapped pressure to the upstream and downstream lines. This would be of particular concern with trapped gas.

Pressure Locking

Gate valves and actuators are normally designed for opening with a differential pressure applied as shown in Figure 2, with loading primarily on the downstream seat. The load required for opening is obviously a function of the seat area, the differential pressure, and the friction coefficients at sliding interfaces on seats and guides. Actuators may not be sized to open a valve against full system pressure P1 if operation is required only for component isolation during shutdown. Since the seating loads shown in Figure 4 are applied to both seats, the opening force with a trapped pressure Pc may be as much as twice that required with the same pressure as an upstream pressure.

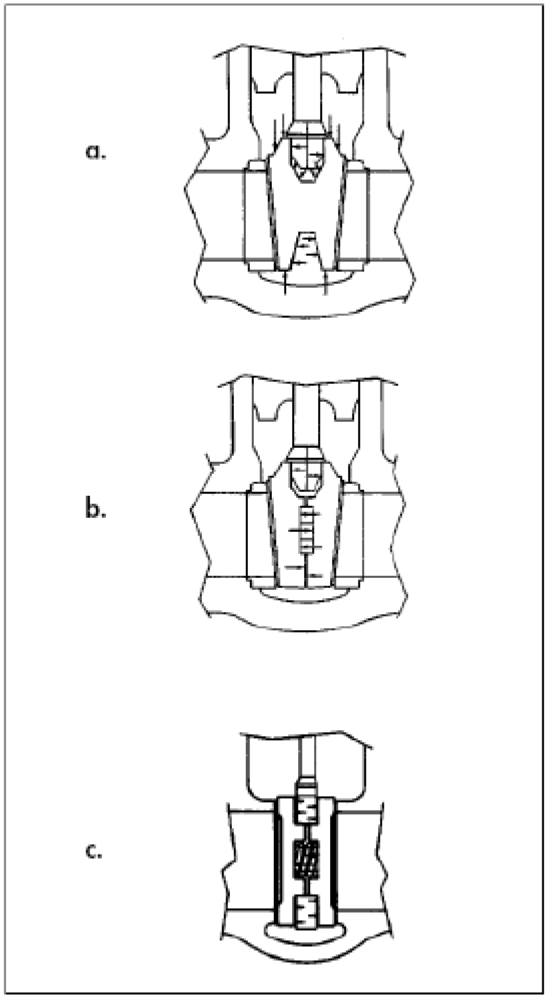

Figure 4: Cross sections of closed valves to show seat sealing loads with both sides of valve de-pressurized:
a. Flexible wedge gate valve
b. Split wedge gate valve
c. Parallel slide valve

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If an actuator is sized for low differential operation only, the required opening force may be much more than that available, and the valve will not be operable in the normal manner. This condition is described as pressure locking.

Heating of trapped fluid in a closed double-seated valve may occur due to conduction and convection in the upstream pipe when a nearby system is heated, as in the start-up of a boiler or a process. Smaller but significant temperature increases may also occur due to seemingly innocuous conditions such as sunlight or a change in ambient temperature. The most extreme known case of center cavity heating arises in the event of exposure of a closed valve to fire; safety in a fire is not normally a design requirement for valves in general industrial or power plant service, but it is often important in refinery and petrochemical applications.

Heating of a constant volume of trapped liquid produces a much more drastic effect on fluid pressure than a corresponding change with trapped gas. According to data in the ASME Steam Tables, an increase in temperature of as little as 40°F can produce an increase in pressure of 3000 psi or more if water is totally restrained from expanding. In practice, the volume of the valve would increase somewhat due to thermal expansion of the metal and elastic expansion under stress due to increasing pressure, but it can be shown that these effects are very small.

The potential for damaging pressure increases should be considered if there is a possibility for heating of trapped liquid in a closed double-seated valve. Even such moderate heating as that due to tropical sunshine might produce a pressure that could be hazardous in some valves.

Some Cases Of Field Problems

Several instances have shown that hazardous pressures may be developed in valves with trapped liquids where temperature increases of several hundred degrees Fahrenheit may occur. In one power plant experience, all internal dimensions in a high pressure gate valve were found to have exhibited a permanent strain (yield) of over one percent after it had undergone a boiler startup, while closed, with water trapped between the seats (from a prior hydrostatic piping test). Since the valve itself had passed a hydrostatic test without damage at, 15 times its 100°F pressure rating after manufacture, it has been estimated that the pressure was 2 to 3 times the valve rating when it was heated in the start-up incident. The valve described above had failed to open due to pressure locking (see above), and the damage due to over-pressurization was not recognized until the valve was inspected to investigate the failure to open. There was no catastrophe, but the pressure had exceeded the valve rating by so much that it is obvious that the safety factor was significantly reduced. This valve was salvaged and returned to service, but extensive rework was necessary to repair the damage that had occurred due to over-pressurization.

In another power plant experience, minor external damage was observed in a gate valve during plant construction. The valve was outside, and it was closed while water-filled after hydrostatic testing. An unexpected cold weather condition produced an ambient temperature below the freezing point of water. Internal inspection of the valve after this incident revealed severe yield of pressure boundary parts, not unlike the conditions observed in the valve that had been over-pressurized (above). This valve was also salvaged and returned to service, but extensive rework was required.

While the methods for avoiding problems are not new to many people in the valve and piping industries, the fact that problems are still encountered occasionally suggests that these solutions are not known widely enough. The specific functional requirements of a valve should be considered carefully in selecting the best approach. Several of the measures in common use and their advantages and disadvantages will be addressed:

• Operating procedures

As suggested in ASME/ANSI B16.34, special plant operating procedures, such as partially opening double-seated valves before starting a heat-up of a piping system, may be quite effective in preventing hazardous over-pressurization. This approach requires (1) identification of valves that may be most hazardous, with trapped liquid, (2) cracking valves away from fully seated positions with handwheels or actuators before start-up, and (3) resealing of valves that must remain closed after heating. This may produce unacceptable leakage in some component isolation valves, and the leakage during start-up may cause seat damage due to erosion. There might still be pressure locking problems during shutdown with both sides of valves depressurized. However, no special valve features are required, and the valve retains bidirectional shutoff capabilities.

• Hole in upstream side of gate or ball

A hole can be drilled in the upstream side of a flexible wedge, two-piece wedge, or parallel seat valve gate as shown in Figure 5; a similar change can be effected in the ball in a floating ball valve.

This change effectively bypasses the upstream seat, assuring that the center cavity pressure Is the same as the upstream pressure. Since these valves are primarily downstream sealing, the only loss in normal unidirectional applications is the extra insurance that would be provided by the upstream seat in the event of downstream seat damage.

While this change may be the simplest one for correction of a field problem or for use of a standard valve out of stock, one disadvantage is that the gate or gate assembly cannot be reversed; reversing a gate assembly is one common method of extending life of parts after extensive valve maintenance, but placing the gate with the hole on the downstream side would cause leakage.

As in the case of following changes with internal and external equalizers, the hole in the upstream part of the gate makes the valve unidirectional to some degree. High leakage would be experienced with many valves if the differential pressure is ever reversed, although the amount of leakage may be limited by the orifice size used for the hole. Some wedge gate valves seal reasonably well at their upstream seats with low and moderate pressures, so a valve with a hole might be suitable for some reversed pressure conditions. High reversed pressures would probably cause significant leakage in all gate valves and might over-stress gates not designed for high differential on the upstream side. If this change is to be made to correct a problem with an installed valve, the manufacturer's recommendations should be obtained.

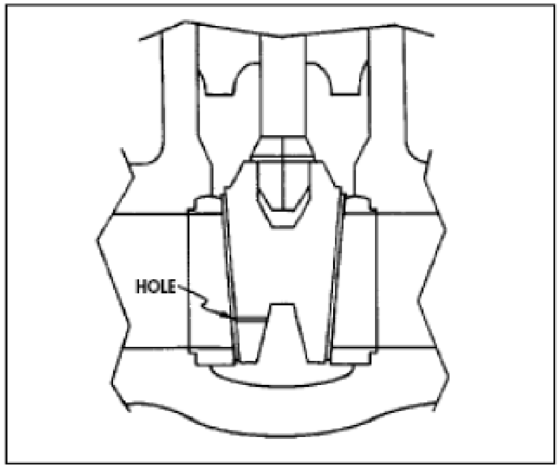

Figure 5: Illustration of hole in upstream gate of gate valve.

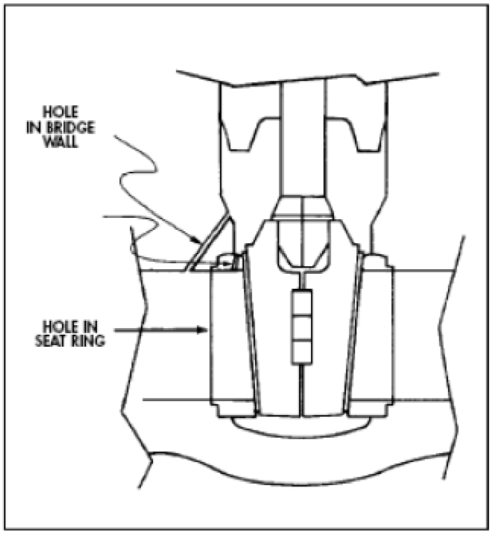

Figure 6: Illustration of hole in upstream seat ring or bridge wall in gate valve (internal equalizer).

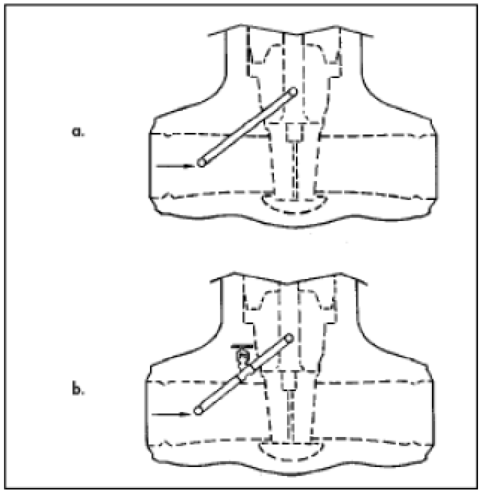

Figure 7: Illustration of pipe between gate valve center cavity and upstream nozzle (external equalizer).
a. Without valve
b. With valve

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• Hole in seat insert or body bridge wall at upstream side (internal equalizer)

A hole in the valve body or seat insert, as shown in Figure 6, bypasses the upstream seat in the same manner as a hole in the upstream side of a gate. A similar change could probably be effected in a ball valve.

As compared to the hole in the gate, this change is preferable from, a long term maintenance standpoint, because the gate or gate assembly could be reversed for extended life. The body drilling would be difficult in an installed valve, but it is easily accomplished during manufacturer of a new valve. The only concern is to be sure that the valve is marked and installed in the proper direction.

This feature might be difficult to modify in a valve in line if there were ever a system change that would require sealing in the reversed direction.

• Pipe connecting center cavity to upstream valve nozzle (external equalizer)– without or with valve

The external equalizer pipe, shown in Figure 7a, also bypasses the upstream seat. The directional nature of the valve should be obvious to one viewing the valve. It can be incorporated in a new valve, or with more difficulty to an installed valve.

This feature would be relatively easy to modify in line if there is a system change requiring reversed seat tightness.

As shown in Figure 7b, a valve (typically a small globe valve) can be installed in the external equalizer and be left normally open (locked open if necessary) to provide the upstream seat bypassing function. Closure of the small valve would permit reversed seat tightness for special purposes (e.g. hydrostatic testing of downstream piping); obviously procedures would have to be enforced to assure opening of the valve before normal operation.

• Connect pressure relief valve to center cavity and connect with piping to a safe discharge point.

A relief valve may be used, as shown in Figure 8, to prevent hazardous over-pressurization of double-seated valve bodies. Codes and standards applicable to overpressure protection devices have to be checked and complied with. The set point has to be enough above the highest normal operating pressure to prevent weepage and inadvertent operation. Since this approach requires an active component (the relief valve), it is not recommended unless the preceding passive approaches are not acceptable. Since the valve center cavity could trap a pressure up to the relief valve set point, pressure locking could still interfere with valve opening with reduced upstream pressures.

Thus the relief valve would offer pressure boundary safety, but it would not ensure operational reliability.

Summary

Double-seated valves have established histories of safe and successful operation in a multitude of applications in general industrial service, as well as in power plants, refineries, and petrochemical facilities. The two seats provide benefits, but some relatively simple technical issues should be considered to prevent problems due to trapped fluid between the seats. Piping system designers, valve users, and valve manufacturers should cooperate to establish the best measures to assure reliability, safety, and sealing effectiveness if a potential problem is identified. Since individual valve applications involve specific functional requirements, a combination of the measures cited above (operating procedures and design features) may be necessary to provide best performance.

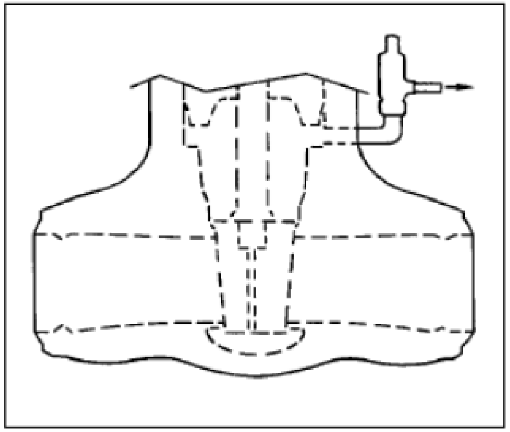

Figure 8: Illustration of relief valve connected to gate valve center cavity.

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