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Controlling Valve Fluid Velocity

In severe-service applications, excessive fluid pressure and velocity result in poor control valve performance and valve failure. Disk-stack trim design can offset the negative effects of these variables.

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Poor control valve performance, exemplified by shortened trim life, internal leakage, poor fluid control, pipe vibration, or excessive environmental noise, can hinder successful plant operation. In the face of these common problems, conventionally designed valves may be a less-than-ideal solution for many plant applications, regardless of their published, critical service specifications.

For the purposes of this discussion, conventional valve design can be characterized by the way each manufacturer approaches trim design. Most valve manufacturers flow process fluids through some version of a single- or multiple-area orifice. Although these designs may perform successfully under normal conditions, common problems encountered in severe-service applications are erratic control, mechanical vibration, noise, cavitation, and erosion, resulting in shortened valve life and increased expense for the user.

Examination of actual flow parameters when these problems exist reveals that the pressure ratio across the valve is greater than three. That is, the absolute inlet pressure of the fluid exceeds three times the downstream pressure. Also, the pressure level is frequently greater than 7 MPa (1000 psi.), although valves been known to receive internal injury at lower- pressures as well. (MPa=mega-pascals, a metric measurement of pressure. 1 MPa = 142.5 psi.)

A second negative factor affecting a valve's duty life is the temperature of the flowing fluid. If the fluid is liquid, it is important to consider its temperature and whether the pressure drop within the valve causes the fluid to vaporize as it drops below the flash point. When the fluid is sufficiently hot, a vapor change can take place, leading to internal valve damage from cavitation and erosion.

In addition to the fluid phase-change problem, absolute temperature level can affect valve design parameters. This has to do with the strength and expansion characteristics of the valve material itself. Valve design must be such that material expansion resulting from temperature does not overstress valve components, with particular attention being paid to parts-expansion characteristics during thermal transients. Temperatures above 300ºC (600ºF) require that specific valve characteristics be accommodated to minimize damage from thermal expansion effects.

Control engineers should be aware that many control valves specified as heavy duty are not actually heavy duty. Valves to be used for severe service, or in operating environments requiring long-term dependability, require careful selection. Where such need exists, the user should choose the valve according to how it functions, as well as its ability to be custom fitted to the application in a cost-effective manner.

Operational problems that cause poor valve performance and failure in service applications are caused primarily by excessive fluid velocity. Even the use of harder materials in the valve to

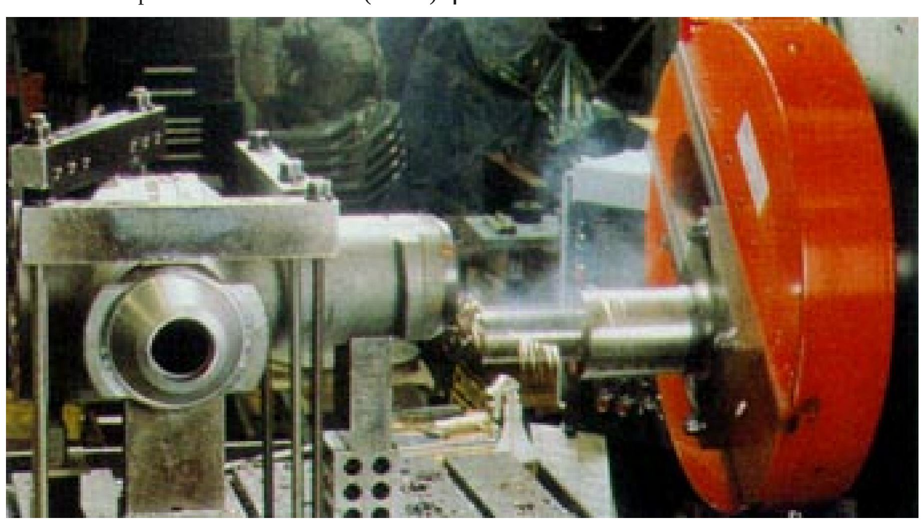

Figure 1. Disk-stack valves offset the negative effects of excessive fluid velocity

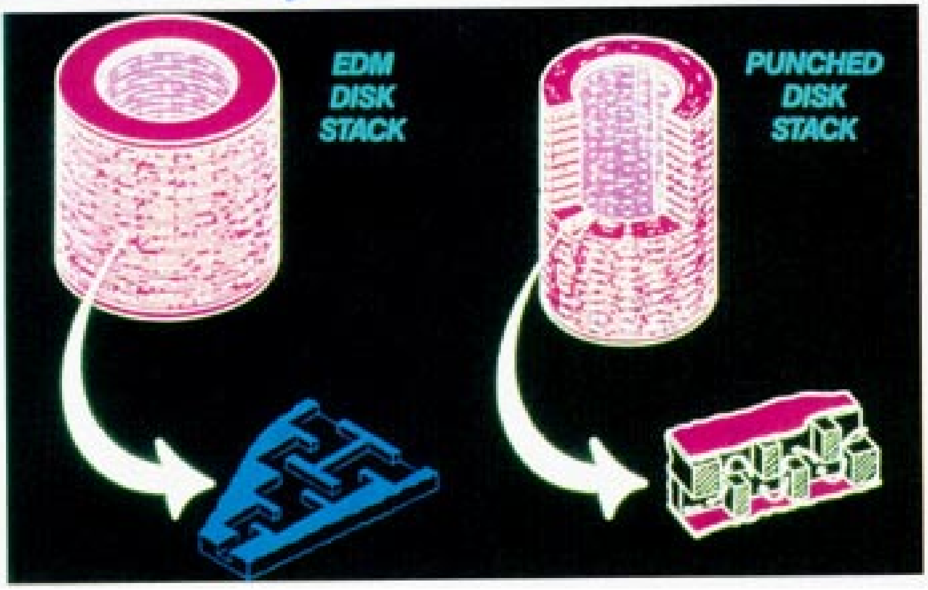

Figure 2. Stacked pathways can be matched or mismatched between individual disks to create a labyrinthal flow pattern.

offset erosion from cavitation, or the use of pipe-lagging or downstream chokes, can only marginally offset valve failure from this cause. Velocity must be controlled at all valve settings in order to maintain performance.

Disk-Stack Trim Design

One way to reduce pressure and velocity is to control velocity by dividing the fluid stream into multiple, but discrete, flow passages and to dissipate the fluid energy (and velocity) in a continuous manner, by inducing controlled turbulence in the flow. Control Components' patented disk-stack trim design, or DRAG technology (Fig. 1), offsets the negative effects of excessive fluid velocity and controls all negative flow and control characteristics in a custom-tunable manner.

This approach uses a series of flat metal disks to form a trim assembly. Each disk has a flow pattern of successive, right-angle furrows cut into its flat surface. When stacked, these pathways can be matched or mismatched between individual disks to create a labyrinthal flow pattern that enables trim to be infinitely tuned to control flow in a manner that maintains positive operating characteristics throughout the valve's opening range (Fig. 2). The flow path for each disk is opened as the plug moves within the center opening of the disk stack. By forcing the fluid to make the tortuous turns required to pass through the stack to the outlet, the desired pressure drop is achieved by a reduction of the velocity head, $pV^2 / 2$, for each right-angle turn. Test results indicate a higher multiple than one velocity head is achieved for each turn encountered. Overall fluid velocity is controlled by into the individual disk stack. Additional velocity control can be achieved by varying the flow area within each pathway (Fig. 3)

This flow method controls the damaging effects of velocity in two ways: by dividing flow into many small streams of low-mass flow rate, and by forcing fluid through a series of sharp turns to affect the pressure-drop steps.

The external appearance of a disk-stack valve is essentially the same as a conventional globe or angle-type control valve, with the disk stack forming a cylindrical valve trim, and the flow rate controlled by the up-and-down movement of the plug. Flow characteristics with these disk-stack trims can be tailored to provide linear or modified linear, or can be characterized in terms of flow-to-stroke ratios.

In a linear stack, all disks have the same number of passages, the same number of turns per passage, and the same flow area. This makes the flow directly proportional to the valve's stroke at constant differential pressure. Installed, the characteristics of such a valve could be selected as quick-opening, equal-percentage, etc., by using a shaped cam in the valve positioner hardware.

In a characterized disk stack, all disks are not the same, but rather are chosen to provide a distinct, variable flow pattern over the full range of the valve opening. In a turbine-bypass application, for example, fine control is needed at low flow rates, while a large flow is needed at the full-open position. This modified linear characteristic is achieved by the lower disks in the stack having fewer flow passages and the stack's upper disks having more passages. On the other hand, the disk stack in a feedwater regulator would provide a modified-equal-percentage profile to handle the variety of pressure drops required over the valve's flow range. With this trim construction, the bottom 20% of the disks have flow passages with many turns, to handle the high pressure drop and low-flow startup conditions when the valve is first opened. The middle-element disks have fewer right-angle turns and more total passages, to handle the intermediate pressure drop and increased flow characteristics required as the valve is opened further. A cage at the top of the stack allows unimpeded flow, with minimal pressure drop as the valve is fully opened.

Erosion By Cavitation

When liquid pressure is reduced to or below its vapor pressure, flashing and bubble formation occur. In a conventional valve with a multiple-orifice trim, fluid enters at pressure P, at velocity V_1. As it moves through the reduced area of the valve trim, it accelerates to velocity V_2 and its static pressure drops to P_2 - a level at or below the fluid's vapor pressure, P_V.

At this point, the fluid boils. As the fluid moves out of the throat of the valve, pressure recovery begins, converting kinetic energy back to potential energy. Full recovery to downstream pressure is indicated at P_3 and velocity V_3- When the recovery pressure exceeds the fluid's vapor pressure, P_V, the just-formed bubbles collapse, causing cavitation. Released energy causes local sur-ace stresses greater than 1400 MPa (200,000 psi), which can erode even stellated trim very rapidly.

In disk-track valves, the controlled velocity trim design prevents vena contracta pressure from dropping to the liquid's vapor pressure,

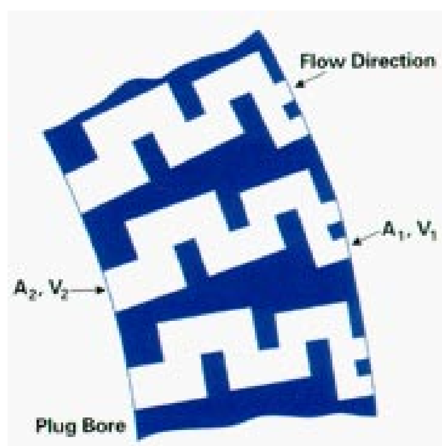

Figure 3. Disk-stack valves control velocity by varying the flow area within each pathway. The outlet area, A_2, is greater than the inlet area, A_1, with a continuously increasing flow area between inlet and outlet.

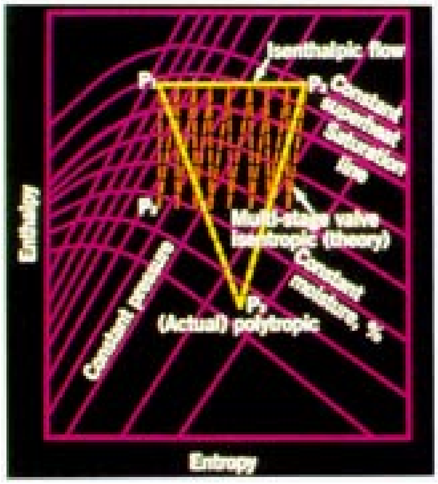

Figure 4. Valve pressure drop leading to trim damage.

provided the outlet pressure is greater than the vapor pressure - thus avoiding cavitation and erosion.

Erosion By Abrasion

Erosion of the valve trim also can be caused by the washing action of a fluid or by abrasion from particles entrained in the fluid. This effect is most severe at high pressures. While clean, dry gases usually are not a cause for concern, throttling even clean, superheated steam can cause severe problems in conventional valves. As shown in Fig. 4, superheated steam at a P_1 of 4 MPa (600 psia) and a T, of 315ºC (600ºF) entering a conventional or modified-trim valve is let down to 0.3 MPa (50 psia). The low pressure and high velocity inherent in flow through these valve trims allow the steam to expand polytropically to point P_3. At this point, with velocity at its peak, the steam develops a moisture content between 12 and 20%. The resulting water droplets, traveling at maximum velocity, will rapidly erode the trim and damage the valve body. Pressure recovery is completed in the outlet and the temperature reaches equilibrium, resulting in superheated steam leaving the valve at a P_2 of 0.3 MPa (50 psia) and a T_2 of 270ºC (515ºF). While the valve has now achieved its pressure drop, continuous formation of wet, high-velocity steam soon will result in severe trim damage. In contrast to this scenario, the disk-stack trim operates at a constant low velocity. With inlet/outlet and trim velocities low, steam expansion through the valve is isenthalpic, going from point P_1-T_1 directly to point P_2-T_2- (An isenthalpic process takes place at constant enthalpy - no external work. It is analogous to isobar, a line of constant pressure on a weather map in the atmospheric measurement of bars.) Steam through this type of valve never has a chance to develop destructive moisture.

The same phenomenon holds true for gas handling services, where hydrate ice crystals can form under similar conditions find clog a conventional valve trim.

Noise

Any valve whose trim allows the development of high fluid velocities will create excessive noise. This can be from the formation of turbulent eddies in the mass-flow stream or from sonic shock waves that develop as fluids hit critical velocity. Downstream noise from valves is unattenuated. In-line mufflers can be used downstream, but they can reduce noise by only 15 to 20 dBA. Applying acoustic lagging achieves about 5 dBA attenuation, assuming it is installed properly - and it is costly and damage prone. When throttling or venting compressibles, near-plant environmental noise levels can reach 120 dBA; and even with modified-trim valves using diffusers, can still exceed 100 dBA.

Because disk-stack technology presents gradual and continuous resistance to flow, fluid velocities are held to well below Mach 1, and can be designed to fall within plant-specified noise limits.

Aerodynamic venting of high-pressure gas is perhaps the most severe offender in environmental noise pollution. Disk-stack technology offers two methods of controlling noise in this context. The first is the use of a fast-acting, pneumatically operated Angle Insert, which would vent excessive steam pressure to the atmosphere, preventing plant safeties from lifting. In this technique, the pneumatically positioned plug modulates the available area of the disk-stack bore for flow control, venting into the atmosphere via a shroud around the disk-stack that directs the flow away, minimizing reactive loading and controlling venting noise.

The second venting method is used with higher mass flows and temperatures. It consists of a velocity control valve coupled with a downstream resistor that is a passive device also employing disk-stack technology to accommodate most of the pressure drop at design flow conditions.

Vibration

Unbalanced, fluctuating pressure forces around the plug can be a serious source of vibration, especially in severe gas and steam service. These forces generate axial and lateral vibrations, even at low pressure ratios, if mass flow rates are high. This results in control instability, aerodynamic noise, and impending trim and piping failure. The abilities of properly applied disk-stack technology to control velocity reduces this problem significantly. Disk-stack valve applications also use complete cage-guiding of the plug, from seat to full-stroke, and the plug is pressure balanced within the stack to counteract axial vibration. **IT**

BEHIND THE BYLINE

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Valve Problems On The High Seas

Shortly after commissioning, a North Sea oil platform began to experience problems with excessive noise on three of its compressor recycle flow control valves. Within three months, the valves were leaking gas in the closed position. They were slower responding in modulation mode than called for in the original specifications, and they exhibited an unacceptable level of instability in positioning, especially between the 0-10% open position.

These globe valves ranged in size from 6 to 12 in., with valve trim sizes of 2 1/2 in., 4 in., and 6 in. Body ratings were API 10,000 lbs. for the 6-in. valve, ANSI 1500 for the 8-in. valve, and ANSI 600 for the 12-in. valve. All were Class V rated for seat leakage, and none were to exceed 90 dBA at 3 ft. Pressure drops across the valves were 200 bar to 10 bar.

When the original supplier proved unable to correct the problem, owners decided that the best approach would be to take the platform's spare valves, machine the interiors for retrofit, and install disk-stack trim. This would save the cost of casting new valve bodies and would also meet critical maintenance deadlines.

Disk-stack trim technology was chosen because the multistage, stacked-disk design would better control gas velocities through the valve as pressures were reduced more than twenty-fold. With better velocity control would come a reduction in noise and the elimination of erosion on the seating face. This would then yield greater control over gas flow. Also, trim and valve design would give platform engineers a quicker response in modulation mode, as well as better positioning stability.

The valves are now performing well. Noise levels are at or below specifications, and the leakage problems have disappeared. Response rates and flow control have improved significantly.