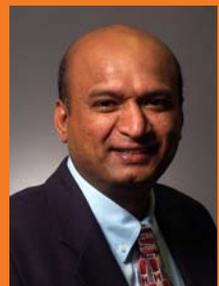


## Specifying surge relief valves in liquid pipelines

Surge relief valves are often the last line of protection for a pipeline, saving the day when all else fails, but only if specified and installed correctly.



By Trilochan Gupta

Probably the most infamous example of a relief valve failing is the nuclear accident at Three Mile Island in 1979, but many other incidents have occurred. In 2005, for example, relief valves were partially blamed for the BP Texas City refinery explosion. In that case, the relief valves opened properly, but they caused a flammable liquid geyser from a blowdown stack that was not equipped with a flare. In other words, the relief valves were installed improperly.

In 1999, a pressure relief valve failed on a 16-inch gasoline pipeline operated by the Olympic Pipe Line Company in Bellingham, Wash., spilling 277,000 gallons of gasoline into the river. The gasoline exploded, killing three young boys. The incident resulted in five felony convictions for Olympic employees and a \$75 million wrongful death settlement.

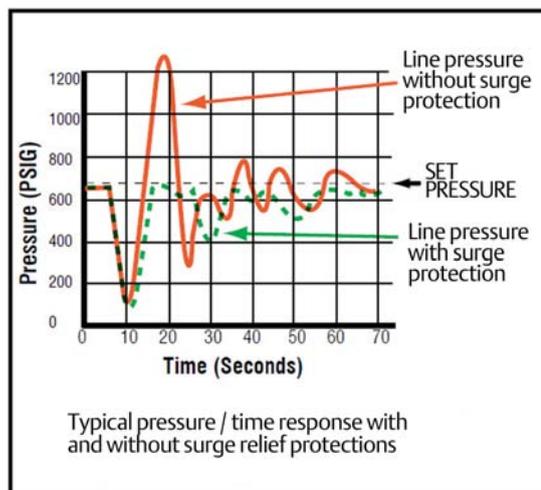


Figure 1: A pressure surge can consist of multiple events, resulting in up to ten times the normal pipeline pressure. When a surge relief valve opens, it vents the pressure to a safety system.

And in 2009, at the Sayano-Shushenskaya hydroelectric plant in Siberia, severe water hammer ruptured a conduit leading to a turbine. A transformer exploded, killing 69 people. It is not known if the plant had surge relief valves, but this is exactly the kind of problem that surge relief valves are designed to solve.

To prevent similar problems from occurring in

an oil pipeline, proper attention must be paid when specifying and installing surge relief valves.

### Pressure surges

In an oil pipeline, pressure surges occur from sudden events, such as a valve closure or a pump trip, often triggered by an emergency shutdown (ESD). The moving fluid in the pipeline acts much like a train when it hits an obstacle; that is, each car slamming into the one ahead causes multiple surges.

The resulting pressure surge can be up to ten times the normal pipeline pressure—and can cause a pipeline rupture, blown valve or pump seals, spillage, and many other problems (Figure 1). The function of a surge relief valve is to quickly open when such a pressure surge occurs in order to relieve the high-pressure fluid to a holding tank or other safe outlet.

### Four events typically induce pressure surges:

- Pump startup: Startup can cause a rapid collapse of the void space downstream from a starting pump. This generates high pressures.
- Pump power failure: This can cause a pressure upsurge on the suction side and a pressure down-surge on the discharge side. The down-surge is usually the ma-



Figure 2: A surge pressure relief valve is an integral part of a complete surge relief system in a pipeline.

### FAST FORWARD

- The pressure resulting from a surge in a pipeline can be up to ten times normal pipeline pressure.
- Two factors determine surge valve sizing: location and setpoint pressure.
- When properly specified and installed, surge relief systems can prevent accidents and damage and increase equipment life.

major problem. The pressure on the discharge side reaches vapor pressure, resulting in vapor column separation.

- Valve opening and closing: Closing a valve at the downstream end of a pipeline creates a pressure wave that moves back toward the reservoir. Closing a valve in less time than it takes for the pressure surge to travel to the end of the pipeline and back is called “sudden valve closure.” Sudden valve closure changes the velocity quickly and results in a pressure surge. The pressure surge resulting from a sudden valve opening is usually not as excessive.
- Improper operation or incorrect design of surge protection devices: Oversizing the surge relief valve or attempting to incorporate some means of preventing water hammer when it may not be a problem can do more harm than good.

Problems can also occur at loading and unloading stations, such as a ship transfer system. For example, excessive surge pressures can be caused by the ship’s breakaway couplings when the ship disconnects or from an ESD valve closure. Both can cause damage to loading hoses or arms, loading buoys, and feed pipework.

In general, all pipelines where pressure is contained must have some form of pressure relief system (Figure 2), which is often required by local or national authorities. In the U.S., for example, Department of Transportation (DOT) guidelines DOT Title 49 CFR Ch.1 Part 195.4064 states: “No operator may permit the pressure in a pipeline during surges or other variations from normal operations to exceed 110% of the operating pressure limit...”

**Selecting a surge relief valve**

The size of a surge relief valve is determined by two factors: location and setpoint pressure. Relief valves should be located nearest to the point where the increased pressure can occur. A simple conventional spring-loaded relief valve is unlikely to operate suf-

ficiently fast enough to relieve a pressure wave as it passes the relief valve nozzle. By adopting the lowest set pressure allowed by a hydraulic transient surge study, the smallest surge relief system design can be used.

Most large pipeline and pipeline design companies have computer programs to model a pipeline, and these programs provide data on how much product must be removed, and in what time frame, to keep line pressure within the 110% limit imposed by the DOT in the U.S. Using these and other data, a pipeline engineer

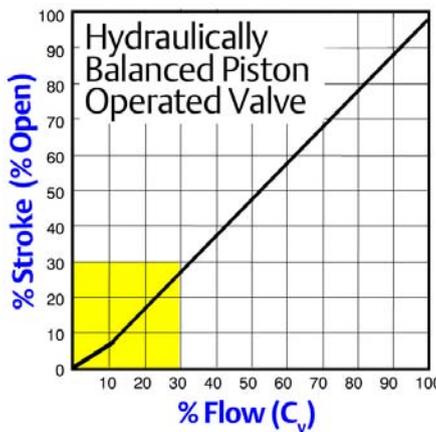


Figure 3: Linear valve characteristic curve for Daniel Model 765 nitrogen loaded surge relief valve, showing valve stroke versus flow ( $C_v$ ).

can select a proper surge relief valve.

Factors that need to be considered include the modulating valve’s response time, valve flow coefficient ( $C_v$ ), excess pressure above setpoint to reach required flow rate, and valve characteristic control curve.

Valve response time refers to the time it takes for a relief valve to open when the pressure setpoint is exceeded. The valve flow coefficient  $C_v$  is the quantity of fluid that will flow through a wide open valve with a 1 psi pressure drop.  $C_v$  varies by valve size, type, and manufacturer.

When a relief valve opens, it is because line pressure exceeds the bias pressure keeping it closed. This bias force varies by type and operating characteristics, such as a balanced or unbalanced surge relief valve design.

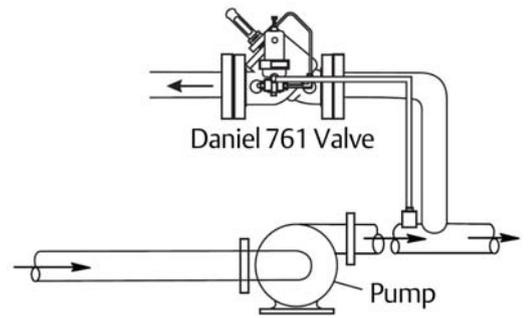


Figure 4: Pilot-operated surge relief valve installed downstream of a pump.

The excess pressure, therefore, defines how much pressure is needed to open the valve.

There are three types of characteristic control curves: equal percentage, linear (Figure 3), and quick opening. For each valve, the type of curve applies to both opening and closing strokes.

Space does not permit a rigorous description of the equations and analyses required to meet these requirements. Because of all the factors involved, a pipeline engineer assigned to the task of selecting pressure relief valves should have a good knowledge of pipeline hydraulics.

**Types of surge relief valves**

In general, two types of relief valves are used in pipelines: pilot-operated and gas- (or nitrogen-) loaded. Both actuate when pipeline pressure exceeds the setpoint, but the gas-loaded valve responds far faster.

A pilot-operated pressure relief valve (Figure 4) is often used for pump protection duty and for applications where the relief valve is required to maintain pressure at a given setpoint. It can control pressure to within  $\pm 2$  psi, regardless of upstream conditions.

The pilot and main valve are usually single-seated valves with high capacities. These valves protect the line against excessive pressure and surge or serve as a pump bypass to maintain a constant pump discharge pressure.

Gas-loaded relief valves are used for pipeline surge relief applications that require quick operating times and valves that can open fully. These valves

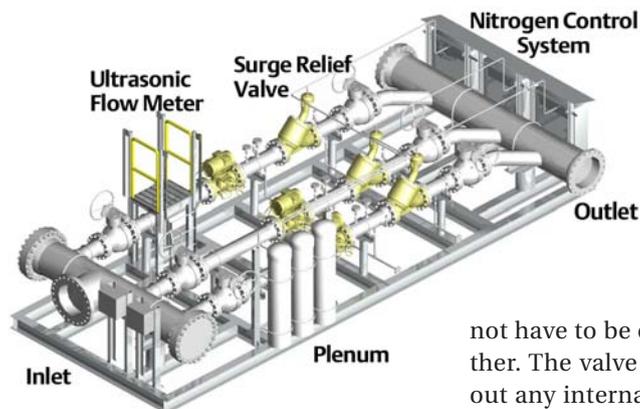


Figure 5: 3D general arrangement view of a typical nitrogen gas-loaded surge relief valve system with ultrasonic flowmeters to measure relief quantity in each stream.

are normally closed and open on increasing inlet pressure. Nitrogen gas is used to pressurize the valve piston in order to keep it in the closed position.

Gas-loaded relief valves incorporate an integral oil reservoir mounted on the external surface of the cylinder head. The reservoir is partially filled with light oil that is used to provide a tight seal, and gas under pressure is applied to the reservoir. This forms the popular gas-over-oil technique. Oil is a barrier between the nitrogen gas (set pressure) and the surge relief valve's piston and cylinder to prevent gas from bypassing the piston, or to prevent a complete setpoint breach of the safety system.

The pressure of the nitrogen gas, minus the force of the valve spring (typically about 4 psi), is the effective setpoint of the valve. When the pipeline pressure is less than this total force, the valve will be tightly closed. As pipeline pressure increases to a level requiring surge relief, the spring and gas pressure are overcome and the valve opens.

A check valve mounted to the internal surface of the cylinder head controls opening and closing speed of the valve. The result is a fast-opening response.

These valves are capable of handling any hydrocarbon liquids, including dirty and viscous fluids such as crude oil or any other heavy oils. The entire internal assembly is removable as a cartridge without the need to remove the surge relief valve body from the line. Because the cover bolt circle on the body of the valve is above the top of the line, it would

not have to be completely drained either. The valve is also designed without any internal parts to obstruct the relief path. This further minimizes debris accumulation, which could inhibit valve operation in any emergency relief responses.

### Designing a surge relief system

The design of a complete surge relief system is dependent upon a complex range of factors, including the potential for pressure increases, the volumes which must be passed by the surge relief equipment in operation, and the capacity of the system to contain pressures. The surge relief system should also work in concert with other safety and control systems.

For example, one of the most difficult surge problems occurs with tankers at loading terminals. If the tanker's ESD valve shuts, the pump continues to operate for a period of time after the valve closes. A better system is for the ESD on the tanker to first shut down the pumps, and then close the ESD valves. Studies indicate that this technique considerably reduces maximum surge pressures.

Control or ESD valve closure times can also affect surge pressures in a pipeline. By extending valve closure time, a more gradual flow decay can be achieved. Pump and pipe sizing are other factors to be considered in hydraulic design.

Predicting transient behavior—commonly termed “surge analysis”—involves detailed computer modeling to simulate the complex interactions of equipment, pipelines, and fluid to normal, fault, and emergency events. Surge transient modeling analysis is not yet subject to codes of practice, so surge relief designs must be based on industry best practices combined with knowledge and experience.

Although many design approaches can help reduce surge pressures in pipelines, a surge relief valve must be installed to protect the system. This is because the surge relief valve is often the last line of defense for a pipeline. If all else fails, a relief valve—as part of a complete surge relief system—can save the day.

A correctly designed surge relief system will include components to dampen or slow the relief valve on closing, and this often requires sophisticated reverse flow plots. In Daniel surge relief valves, for instance, a check valve provides unrestricted flow when opening and a reduced orifice to limit closing speed. This allows a user to set different closing speeds as required by the system.

In nitrogen-loaded valves, attention must be paid to the nitrogen gas system. The nitrogen system must supply a constant pressure (setpoint) to the modulating valve, even under conditions of varying ambient temperatures. Normally, the system is designed to use standard gas bottles and has its own control system to regulate the nitrogen supply pressure.

Supply pressure should be set at the relief pressure required. The gas pressure setpoint, minus the force exerted by the spring, is the surge relief pressure for the system. The nitrogen gas tank could be buried underground or insulated to keep the gas at a constant temperature. Thermal expansion, caused by the increases in temperature of the nitrogen gas, can change the relief setpoint.

Surge relief systems often require correctly sized inlet and outlet manifolds with isolation valves upstream and downstream of the surge relief valves. These are normally full-port ball valves, as they provide least resistance path in the line of relief. A full bore liquid ultrasonic flow meter can also be employed at the outlet of each surge relief valve to determine the relief quantity during each valve cycling (see Figure 5).



Figure 6: Complete surge relief systems can be provided on a skid, minimizing on-site construction.

### Surge control on a skid

One common solution for a pipeline engineer is to have a surge relief system on a skid (Figure 6). Daniel Measurement and Control, for example, offers factory-tested skid-mounted surge relief systems that have prop-

erly sized surge relief valves, manifolds, and piping. These skids feature appropriate provisions for maintenance and a nitrogen charging control system.

A typical surge relief system skid has redundant, parallel surge relief valves; inlet and outlet manifolds sized to minimize the pressure loss; and a nitrogen system. All of these components are integrated on the skid, along with other required equipment, control system, and instrumentation.

Piping runs include the necessary

instrumentation, including pressure and temperature indicators and transmitters, full bore in-line ultrasonic flowmeters, and a nitrogen control system. When properly specified and installed, surge relief systems can prevent accidents, reduce maintenance, and extend equipment operating life. The design of these systems can be quite complex as many factors must be taken into account and various standards must be met.

The consequences and risks of a surge event can perhaps be avoided with an increased level of engineering at the implementation stage. Surge relief systems are best designed and installed by specialized surge relief valve OEMs. These systems can be designed for on-site installation or supplied on a skid ready for installation at the site.

#### ABOUT THE AUTHOR

**Trilochan Gupta** is director of Daniel Measurement and Control Asia Pacific at Emerson Process Management, Singapore. He has worked with Emerson for 18 years in a variety of roles in the area of hydrocarbon flow measurement and control. Gupta holds an honors degree in engineering from University of Bombay and has contributed more than two dozen publications on a variety of topics on flow measurement and control in peer-reviewed journals.

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