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Sliding-plug surge relief valve helps meet DOT requirements

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Controlling transient surges in liquid pipe lines is complex and requires considerably more than a simple "rule-of-thumb" approach. It is a vital phase of pipe line design and can involve potentially large dollar and physical losses, if inadequate.

Complete unsteady-state analysis is required to properly determine not only if surge transients will occur, but also the best design techniques to abate surges.

Under Department of Transportation (DOT) regulations, pipe line operators, must provided adequate controls and protective equipment to control pressures within 110% of the line's operating pressure limit during surges. Axial-flow, gas-loaded relief valves can provide a cost-effective efficient way to provide protection for most pipe lines.

Hydraulic systems, from simple household water piping to complex petrochemical processes, is subject to "water hammer" (surge pressures) if something causes the fluid velocity in the pipe to change suddenly. Typical pipe line causes are pump failure, rapid block valve closing, a non-return check valve slamming shut, emergency shutdown (ESD) of a tanker loading system, or a pump coming on or tripping. The magnitude of surge pressures vary from virtually undetectable to severe enough to cause major damage.

When rapid flow-rate changes occur in a pipe line, pressure waves are generated which travel upstream and downstream from the point of origin. Pressure in the line behind these propagating waves increases or decreases rapidly. This is commonly known as hydraulic transient surge of "water hammer." Typical propagation velocities range from 1,100 feet per second (fps) for a water line to 3,300 fps for a typical crude oil line.

Hydraulic systems are subject to water hammer when fluid velocity in the pipe line suddenly changes

The following simplified equation provides a rough estimate of the maximum surge pressure in a liquid-filled pipe line when a surge occurs:

P = 0.8 wV ("Pipeline Rules of Thumb Handbook"—page 270)

where P = surge pressure, psi

w = liquid weight per cubic foot, pounds

V = velocity change, feet per second

A quick generality is for each foot/second fluid velocity change, pressure will change about 50 psi. For example, a pipe line operating at 400 psig pressure with a fluid velocity change of 10 fps will undergo a pressure rise of 500 psi. This rise added to the operating pressure of 400 psig means the line will be subjected to a pressure surge of 900 psig. For an ANSI 300# class system, 900 psig surge pressure is above the maximum allowable working pressure (MAWP) of the system.

The dashed line in Fig. 1 shows typical pressure/time history obtained downstream of a pump station following pump "trip." As pumping stops, flow into the pipe line drops rapidly, but the liquid colulmn in the line continues flowing from its own momentum leaving behind a low-pressure region. Eventually an opposing force from a static head overcomes the momentum, which in turn accelerates the liquid column back towards the pumping station.

The pump discharge non-return check valve closes during this process. In turn, a rapid pressure rise occurs as the pipe line fluid impinges on the closed valve. The initial pipe line fluid velocity, the static head, the pipe length, pipe material, and internal friction all influence the magnitude of initial pressure drop and subsequent pressure rise.

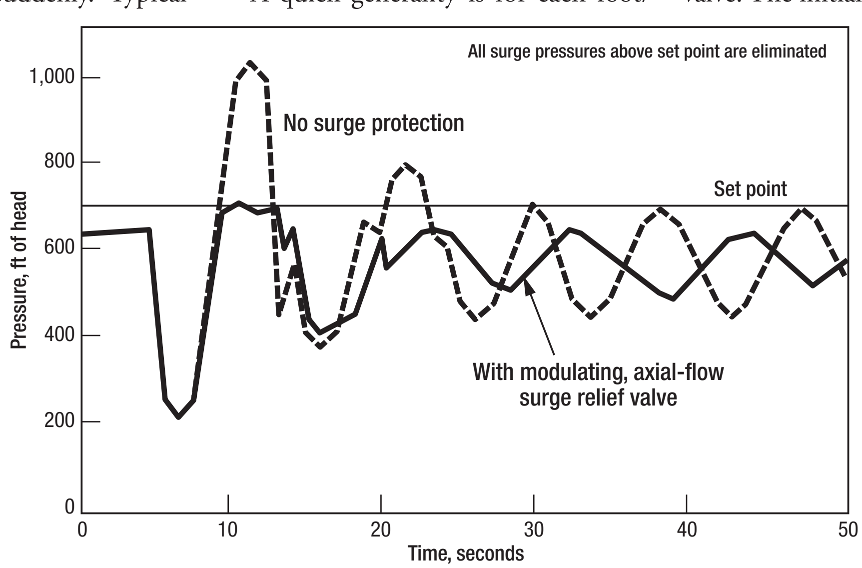

Fig. 1. Typical pressure/time history with and without surge relief protection.

The solid line in Fig. 1 shows a typical pipe line schematic with a pump, a length of line, and a gate valve. Surge effects from valve closure are best explained by considering first the flow through the valve and then incorpo-

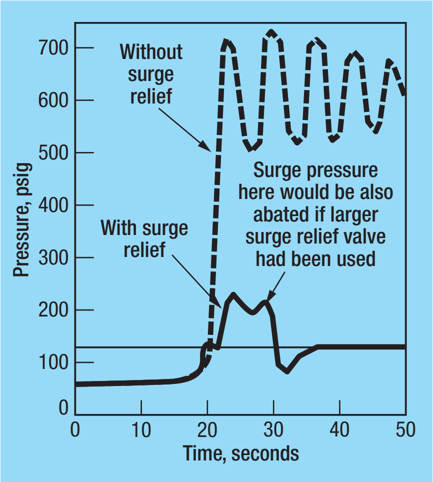

Fig. 2. Pressure/time history at an EDS valve.

rating the pump and pipe line.

As the valve closes and starts to restrict flow, upstream pressure rises and downstream pressure falls. Initially, the pump is delivering flow from A to B at a velocity V through the length of pipe line L. As the valve at B suddenly nears shut-off, the flow rate at B is reduced, causing increased upstream pressure. This pressure rise is transmitted back through the system at the calculated wave velocity so the effects of valve closure are first experienced at the pump in L/C seconds (length in feet divided by wavespeed in feet per second) after the flowrate decreases at the valve.

Due to this pressure increase, the flowrate at the pump falls to a new low value, dependent upon the pump head/flow characteristics. This flow change is then transmitted back down the pipe line to the valve where effects are experienced in 2 (L/C) seconds (or one pipe line period) after valve pressure. Fig. 2 similarly graphs typical pressure/time effects upstream of a valve closure.

In addition to the surge pressure created by rapid valve closure, long pipe lines also are subject to a long, slow pressure rise phenomenon known as "line pack." To overcome frictional losses in the pipe line, pumps must generate higher discharge pressure to move the liquid column downstream. Pump flow is maintained for a substantial time after valve closure as the pump continues to pack the line. In most cases, pressure oscillation in the line during this period results in a final pressure locked between the pump non-return check valve and closed pipe line valve, which will exceed the maximum pump discharge pressure.

Inadequate surge protection. Without proper surge protection, various mechanical problems can and often do arise. Here are the more common ones;

- Axial separation of flanges
- Pipe fatigue failure at welds
- Longitudinal pipe splits
- Pumps knocked out of alignment
- Severe damage to piping and piping supports
- Damage to specialized components such as loading arms, hoses, filters, bellows, etc.

Controlling surges. The Joukowski equation for change in head pressure is:

$$h = C\Delta V/g$$

where h = head change
C = wavespeed
V = fluid velocity change
g = gravitational constant

The gravitational constant cannot be changed, and the wavespeed of the flowing media stays basically constant. The only variable, therefore, is ΔV. This means the key to surge control is to keep the fluid-velocity change (ΔV) down in steps to stay within the pressure rating of pipe and fittings.

Various design approaches to alleviate surge pressure in pipe line include:

- Complete computer modeling of pipe line profiles during initial stages of line design
- Staged pump shut-down sequences
- Linked ships/shore ESD (loading and off-loading tankers)
- Staged emergency shut-down or motor-operated actuators to control valve closure times
- Selection of proper surge-pressure relief systems, including determination of the lowest set pressure and location immediately upstream of critical ESD or motor-operated valve (MOV) valves or other sources of surge pressures.

A completed computer model of pipe line profile should be completed early in the design stage. Computer-based simulation techniques are used be experienced engineers to determine the effects of unsteady liquid flow transmission in the line and piped networks. Solutions to operational and control problems indetified during this phase can be evaluated and verified.

Staging pump shutdowns in conjunction with closing main pipe line valves can help cancel the high-pressure wave traveling upstream fro ma closing ESD or MOV valve. Pump shutdowns can be controlled from remote or local high-pressure or low-flow sensors.

Tanker loading surge control. One of the most difficult surge problems occurs during tanker loading. Historically, if the tanker's ESD valve shuts in, the pump continues to operate for some time after valve closure. Surge pressure conditions previously outlined usually occur.

The surge pressures can be reduced or eliminated by incorporating a linked ESD system where ESD is initiated aboard the tanker to trip the pumps. A proper ESD-valve closure time allows pipe line flow to decay slowly. Such a system must insure that transfer-pump shutdown occurs first. Studies have confirmed this approach provides considerable reduction in maximum surge pressure.

As previously discussed, valve closure time effects surge pressures in any pipe line. Closing cycles of various styles of valves can be used in considering total closing time to achieve a more gradual flow decay.

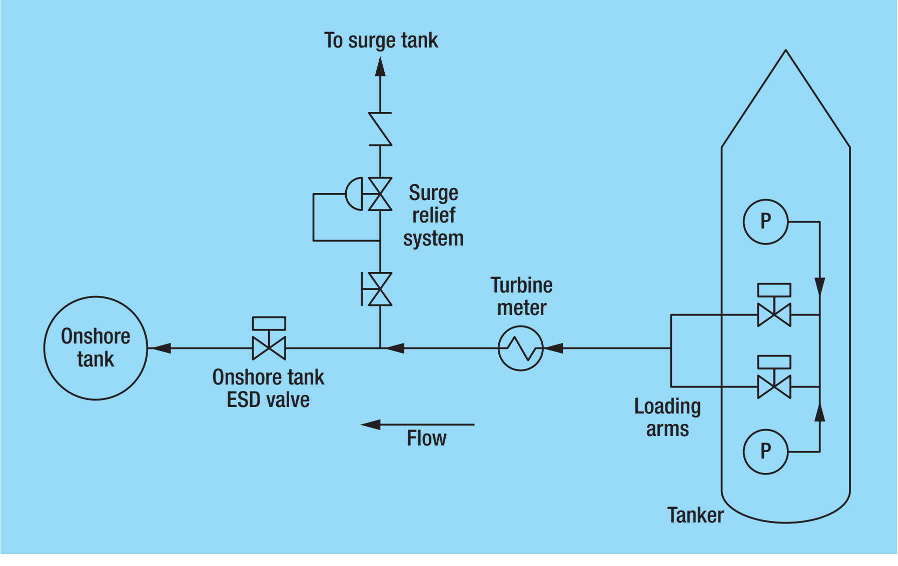

Fig. 3. Tanker off-loading layout.

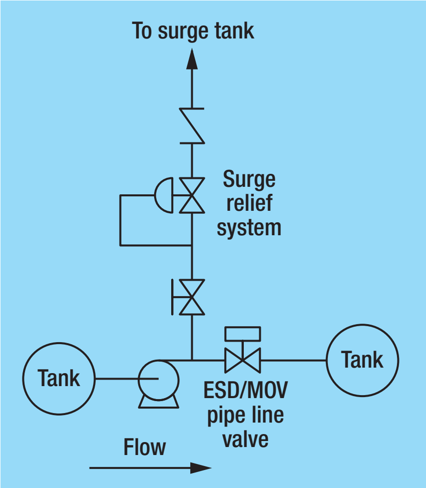

Fig. 4. Typical pipe layout.

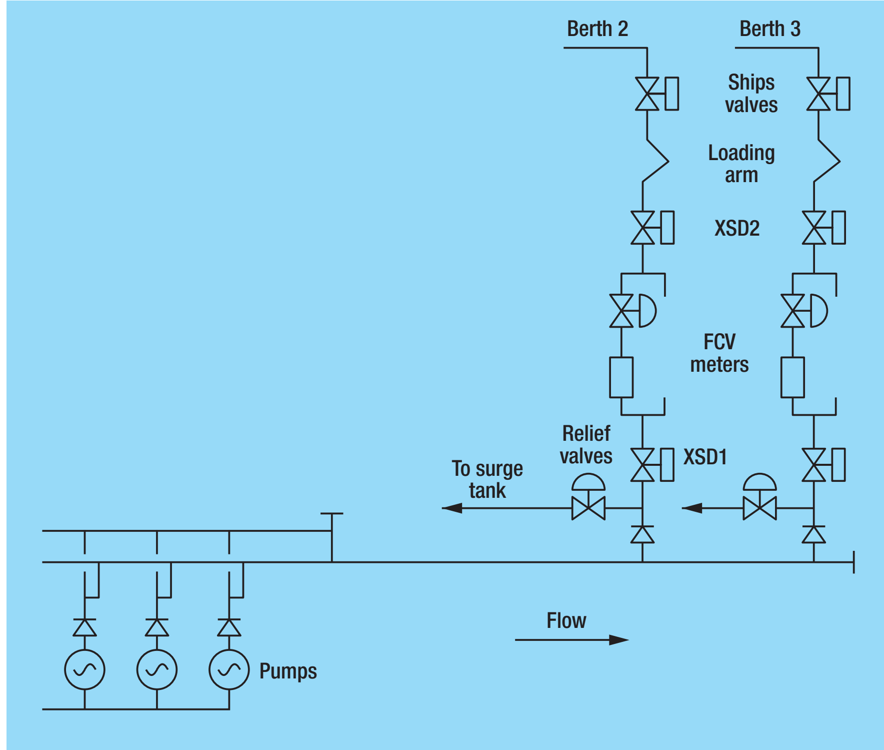

Fig. 5. Tanker loading layout.

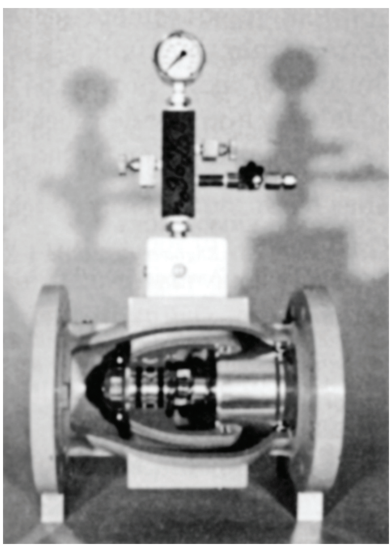

Fig. 6. Versatile axial flow surge relief valve with sliding plug

Fig. 7. Axial flow surge relief valve in test loop.

Surge pressure relief. Although the above design approaches help alleviate surge pressures in pipe lines, a properly designed surge-pressure relief facility will insure system protection. The type and location of a relief facility is governed by two factors: set pressure and location.

By using the lowest set pressure allowed by a hydraulic transient surge study, the smallest and most inexpensive equipment can be used. All relief facilities should be located nearest the point where increased pressure can occur—the main pipe line ESD or MOV valve. Figs. 3, 4 and 5 illustrate recommended locations of a surge relief system for typical pipe line ship-loading/unloading installations.

Once the surge relief facility location ahs been decided, the next decision is what type of surge-abatement equipment to install. Three types are available.

• **Accumulators** are gas pre-charged bladder type vessels, which expel the products immediately back into the system. They are ready for immediate reuse after a pressure surge has occurred. The main disadvantage to bladder systems is that a single accumulator can relieve only a small amount of liquid. A large bank of accumulators may be required, and this is expensive and requires additional space for installation.

• **Rupture discs** relive as a specified setpoint and provide high-volume relief. The main disadvantage is the discs must be replaced after rupture, and the system must be shut in to do this. The downtime of depressurizing the line, replacing the disc, and re-pressurizing is onerous in most cases. Another disadvantage to rupture discs is the tendency towards metal fatigue with resultant premature relief and the operational problems associated.

• Relief valves can handle large liquid volumes and will automatically return to its normal closed position immediately after surge pressure relief so as to provide continual protection. Two types are available: spring-loaded and gas-loaded.

Although spring-loaded safety valves are sometimes used, they can present a problem. Because they use a full-rated spring, they can slam open and closed during relief; this "chattering" can create secondary surge waves. Furthermore, liquid relief capacity is usually limited.

The relief valve which has gained widest acceptance and become the choice for most users I the gas-loaded axial-flow style valve.

These valves are direct acting. They track and abate peak surge waves before the pressure rises above the operating pressure of the pipe and fittings during a transient surge event. They automatically return to the normal closed position as the surge wave decays so as to provide continuous protection automatically.

Gas-located axial flow relief valves (Fig. 6) offer the best overall protection in surge systems. Nitrogen gas charges the relief valve to a recommended valve set pressure. Anytime a surge pressure rises above the set pressure it immediately forces the sliding plug full open for unrestricted axial flow through the valve. The valve thus automatically opens and closes in direct response to pressure increase and decay in the pipe line.

Fig. 7 shows pressure/time histories for the configurations of Fig. 1 and 3 modified by adding the modulating surge valve protection.

When selecting pressure relief equipment, it is important to examine equipment as well as the dynamic response of the piping system, preferences of engineering and maintenance personnel, plus any design constraints that may be applicable because of product or terrain over which the pipe line travels.

Conclusion. With employee safety and environmental concerns added to those over equipment protection, it is obvious that all liquid pipe lines must be protected. For example, DOT "9 CFR Ch. 1 (10-1-88 Edition)" states: "(b) No operator may permit the pressure in a pipe line during surges or other variations from normal operations to exceed 110% of the operating pressure limit established under paragraph (a) of this section. Each operator must provide adequate controls and protective equipment to control pressure within this limit.

The author

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The use of axial-flow gas-loaded relief valves can provide reliable and cost-effective protection for most pipe lines.

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