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CONTROLLING SURGES IN LIQUID PIPELINES

Class # 6020.1

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Introduction

Numerous technical papers have been written on unsteady state surge flow or "water hammer". This paper, unlike many of its predecessors, will present a view adapted to the engineer/technician who, for one reason or another, only needs a basic understanding of why surge occurs and how to control it.

This paper will discuss the following topics:

1. History
2. Definitions/terminology
3. Why surge occurs
4. Problems from inadequate surge protection
5. Controlling Surges

History

Recorded studies of unsteady state flow observations and analysis in pipelines began in the mid-nineteenth (19th) century.

In the early 1850's, Wilhelm Weber measured the effects of pipe wall elasticity on wave propagation speed. Continuity and fluid dynamic equations, which were developed by Mr. Weber, were the basis for later analytic studies.

Probably the two- (2) most important people who made contributions to the history of hydraulic surge studies were Nicolai Joukowski and Lorenzo Allevi.

Nicolai Joukowski, a Russian engineer, demonstrated in 1898 that the pressure rise in a water line was directly related to the change in fluid velocity, the wave speed and fluid density. Due to the extensive work Joukowski performed, he is considered the father of water hammer analysis.

In 1913, Lorenzo Allevi, an Italian, created a mathematical and graphical treatment of water hammer that became the foundation for further technical and analytical developments in the field for the next fifty (50) years.

During the 1930's and 1940's, graphical techniques were greatly improved. Further refinements in mathematical models allowed a more general form of basic equations to be used.

Besides the technical work done by Joukowski, Allevi and others, the creation of high-speed computers in the 1960's began a new era in hydraulic transient surge analysis. Previously, analytical surge study work that took several weeks to complete could now be performed within hours. Surge analysis became a portion of the scope in a pipeline project.

Terminology

To understand surge, its causes and cures, one must have a basic understanding of the most common terms used in pipeline hydraulics. These definitions are the ones used most often in the pipeline industry. Occasionally, other published documents may use the same term but with a different meaning.

ESD System

An Emergency Shut-Down System which, initiated either manually or by automatic control sensors, enables rapid and effective shutdown of relevant operations and equipment in a safe and controlled manner.

Surge Pressure

The rapid change in pressure, as a consequence of a change in flow rate, in a liquid pipeline.

Pipeline Period

The time required for a pressure signal to travel the length of the pipeline system in use from one end to the other end and back again. The time is twice the length of the pipeline divided by the wavespeed.

Wave speed

The velocity of sound in the fluid when flowing in a pipe, and is the speed at which surge pressures are transmitted along a pipeline.

Total Shut-Down Time

The time required from manual or automatic initiation of ESD to final closure of ship or terminal manifold valves.

Signal Response Time

The time between initiation of ESD and the recognition of the initiating signal by the ESD system (For example, the time between initiating ESD at a remote control and the operation of the ESD interface units in the main control center).

Actuation Response Time

The time between recognition of an ESD signal by the ESD system and the commencement of the required actuation. The Actuation Response Time occurs immediately following the Signal Response Time. (For example, the time between operation of the ESD interfaces units in the main control center and the commencement of an ESD valve closure).

Total Valve Closure Time

The time required for a valve to move from the open to the closed position.

Effective Valve Closure Time

The period over which an ESD valve reduces the flow from 90% of its steady state to zero. (In relation to Total Valve Closure Time, this is typically about the last 5% for gate valves, about the last 15% for butterfly valves, about the last 25% for ball valves and about the last 30% for plug valves, when these ESD valves are at the end of a long pipeline system).

Why Surge Occurs

1. Starting or stopping of a pump
2. Closure of an automatic emergency shutdown device (ESD)
3. Rapid closure or opening of a manual or power operated valve.
4. Slamming shut of a non-return (check) valve

Any hydraulic system, from a simple rising water main to that of a complex petrochemical process network, will be subject to surge pressures if operational changes cause velocity fluctuations. Such actions may vary from the routine failure of a pump to the emergency shutdown of tanker loading systems. Similarly, surge pressures may vary in magnitude from being virtually undetectable to having sufficient severity to cause a major disaster.

Rapid changes in pipeline flow rate usually caused by pump shutdown or valve closure generate pressure waves, which travel upstream and downstream from the point of origin. The pressure in the pipeline behind these propagating waves is very rapidly increased or decreased. This is commonly known as hydraulic transient surge or water hammer. Typical propagation velocities can range from 1100 ft/sec to 3300 ft/sec (335 – 1005 m/sec).

To obtain a rough estimate of the maximum surge pressure in a liquid-filled pipeline when a surge event occurs, the following simplified equations can be used:

$P = .8wV$ (PIPELINE RULES OF THUMB, Page 335)

where P = surge pressure, PSI
w = weight of liquid per cubic foot, lb.
V = velocity change, ft/sec

For quick reference, for each foot/second fluid velocity there is approximately a 50-psi pressure rise. For example if the pipeline operating pressure is 400 psig with a fluid velocity of 10 ft/sec, the approximate pressure rise is 500 psi. The pressure rise of 500 psi is added to the operating pressure of 400 psig for a total pipeline pressure surge of 900 psi. If this is an ANSI 300# rated system, the 900-psi surge pressure would be above the MAWP of the system.

Surge pressures are most likely created by one of the following:

Pump Trip

As a pump fails, flow into the pipeline drops rapidly, but the column of liquid in the pipeline continues under its own momentum leaving behind a low-pressure region. Eventually, the momentum is overcome by the opposing force of a static head, which in turn accelerates the liquid column back towards the pumping station. The pump discharge non-return check valve closes in this interim period and hence a rapid pressure rise occurs when the pipeline fluid impinges on the closed valve. The magnitude of the initial pressure drop and subsequent pressure rise is influenced by the initial pipeline velocity, the static head, the pipe length, material and friction.

Sudden Valve Closure

The surge effects due to valve closure are best explained by considering flow through the valve alone and then incorporating the pump and pipeline in which it operates. As the downstream valves closes and starts to restrict flow, the upstream pressure rises and the downstream pressure falls. A pump is delivering flow in a pipeline at a certain velocity through the length of the pipeline. If the downstream valve closes suddenly to half open, the flow rate downstream is reduced causing an increased upstream pressure. The pressure rise is transmitted back through the system at the calculated wavespeed, so that the effects of valve closure are first experienced at the pump L/C (pipeline length divided by the wavespeed) seconds after the flow rate decreases at the valve. Due to this increased pressure, the flow rate through the pump falls to a new value, dependent upon the pump head/flow curve. This change in flow is then transmitted back down the pipeline to the valve, where the effects are experienced in two (2) L/C seconds or one Pipeline Period, after the valve movement.

In addition to the surge pressure created by rapid pipeline valve closure, long pipelines are also subject to a long, slow pressure rise phenomenon known as line pack. Due to frictional losses in a pipeline, pumps must generate higher discharge pressures to move the liquid column downstream. Pump flow is maintained for a substantial period after valve closure as the pump continues to pack the pipeline. In most cases, the final pressure locked in between the pump non-return check valve and the closed valve exceeds the maximum discharge of the pumps, due to pressure oscillation in the line during this packing period.

Problems from Inadequate Surge Protection

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

Controlling Surges

The Joukowski equation is as follows:

$$h = \frac{C\,\Delta V}{g}$$

where h = head change
C = wavespeed
ΔV = Fluid Velocity change
g= gravitational constant

The gravitational constant cannot be changed and the wavespeed of the flowing media stays basically the same. The only variable in the equation is the delta V. The key to surge control is to bring the delta V, fluid velocity change, down in steps to stay within the pressure rating of the pipe and fittings.

Some design approaches to alleviate surge pressures in pipelines are:

1. Complete computer modeling of pipeline profile during initial stages of pipeline design work.
2. Stage pump shutdown sequence
3. Linked ship/shore ESD (Loading and off-loading tankers).
4. Stage emergency shutdown or motor operated valve closure times.
5. Select proper surge pressure relief system.
   A. Lowest set pressure
   B. Location - immediately upstream of critical ESD or MOV valve or other source of surge pressure

A complete computer model of the pipeline profile should be completed early in the design of the pipeline. Computer based numerical simulation techniques are used by experienced engineers to determine the effects of unsteady flow of liquids transmission and pipelines and piped networks. Operational and control problems are identified during this phase and proposed solutions verified.

Staging pump shutdowns in conjunction with the closing of main pipeline valves can help cancel the high-pressure wave traveling in the opposite direction from the closing ESD or MOV valve. Pump shut downs can be achieved by the use of a remote or local high pressure or low flow sensor.

One of the most difficult surge problems occurs during tanker loading at loading terminals. Historically, if the tanker's ESD valve shuts in, the pump continues to operate for a period of time after the valve closure. The surge pressure conditions discussed previously usually occur. Surge pressures can be reduced or eliminated by incorporating a linked ESD system. This system uses the initiation of ESD on board the tanker to trip the pumps. The ESD valve closure time allows the pipeline flow to decay. These systems must insure the transfer pump is shutdown first. By utilizing this design concept, studies have shown considerable reduction in maximum surge pressures can be effected.

As discussed previously, valve closure times can affect surge pressures in the pipeline. By extending the valve closure time, a more gradual flow decay can be achieved. Closing cycles of different styles of valves, e.g., ball, butterfly, globe or gate valves can also affect the flow decay.

Although all of the above design approaches help alleviate surge pressures in pipelines, a surge pressure relief facility should be installed to protect the system. The type and location of the relief facility is governed by two factors, i.e., set pressure and location.

By adopting the lowest set pressure allowed by the hydraulic transient surge study, the smallest relief system design can be used. All relief facilities should be located nearest the point where the increased pressure can occur, e.g. main pipeline ESD or MOV valve.

Once the location of the surge relief facility is decided upon, the next decision is what type of relief facility to install. There are three (3) forms of relief devices available.

The first type of relief device is an accumulator. These are gas precharged bladder type vessels that expel the product immediately back into the system. They are ready for immediate reuse after a pressure surge has occurred. The main disadvantage to this type of system is that singular accumulators can only relieve a small amount of fluid. If a large pipeline system is being used, a large bank of accumulators may be required. This could be very expensive and require additional space to install.

Rupture discs are a second type of relief device. When they relieve at their set point, they can provide a high relief flow capacity. Their main disadvantage is that the relief system has to be shut-in to replace the rupture disc. Before the disc can be replaced, the pipeline usually has to be de-pressurized, the disc changed out and then re-pressurized. Down times of a pipeline or loading facility can be expensive. Another disadvantage of rupture discs is that sometimes metal fatigue of the disc can occur and cause premature relief, which can create additional operational problems.

The third type of relief mechanism used is a relief valve. There are two (2) types of relief valves, spring loaded and gas loaded.

Although spring loaded safety valves are sometimes used, their main disadvantage is that because they use a full rated spring in their design, it can slam open and closed during relief operations, chattering, thus causing secondary surge waves to occur. Additionally, relief capacities are limited.

Other types of relief valves that have gained wide acceptance and have become the surge relief valve(s) of choice are the pilot and gas-loaded axial flow style valves. These valves are an excellent choice for surge relief service because they are direct acting. They can track and abate peak surge waves before the pressure rises above the operating pressure of the pipe and fittings during a transient surge event.

Pilot operated axial flow relief valves are generally limited for use in refined or clean media products pipelines. Pilot operated valves should never be used in crude oil pipelines.

The gas-loaded axial flow relief valve probably systems. Nitrogen gas is used to charge the relief valve with the recommended valve set pressure. The valve is designed to sense an immediate surge pressure rise. As soon as the pressure rises above the set pressure, the gas-loaded relief valve will open. The valve opens and closes in direct response to the pressure rise and decay of the pipeline.

When selecting pressure relief equipment, it is important to look at the dynamic response of the piping system, as well as the preferences of the pipeline engineering and maintenance personnel, the product and any design constraints that may be applicable.

With employee safety and environmental concerns a major consideration in today's industry, all liquid pipelines must be protected. Controlling surges in liquid pipelines should always be one of the major aspects of pipeline design.

SUMMARY

Controlling transient surges in liquid pipelines is a very complex task. It is one of the more important phases of pipeline design. A complete unsteady state analysis is required to determine not only if surge transients will occur but the best design techniques to abate these transient events.

REFERENCES

1. Keech, Andrew. The Engineering Significance of Pressure Surges. Hydraulics Analysis LTD. HORSFORD, LEEDS, ENGLAND.

2. The Society of International Gas Tanker and Terminal Operators LTD (SIGTTO). Guidelines for the Alleviation of Excessive Surge Pressures in ESD. Witherby & Co. LTD. LONDON. EC1, ENGLAND, 1987.

3. Waters, Gary Z. Analysis and Control of Unsteady Flow in Pipelines. Butterworths Publishers, 1984.

4. Pipe Line Rules of Thumb Handbook. Gulf Publishing Company, 1993.