# *Avoiding Pressure Surge Damage in Pipeline Systems?*

**Abstract**: *Pressure surges occur in all fluid pipeline systems. There arise two types of damage from the surge phenomenon, fatigue and catastrophic failure. This paper addresses this phenomenon from the viewpoint of the available solutions rather than the mathematics and modelling involved in determining the quantum of the surge pressure.*

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Many thanks are given to the researchers and professionals in this field for sharing their knowledge and enabling this paper to be prepared. These include Prof ARD Thorley, Prof BW Gould, Mr T Webb, Prof BE Wylie, Prof VL Streeter, Prof L Suo, Prof Dr JA Swaffield, Prof AP Boldy, Prof N Lawgun and others. They have all made the topic of surge analysis a more widely understood technology and have provided the tools to model and solve some problems for industry. This paper has been peer reviewed by Trey Walters CEO of Applied Flow Technology www.aft.com and Graeme Ashford Principal of Accutech Pty Ltd www.accutech2000.com.au .

Further papers on the Risk of Surges in Pipeline Systems can be found at www.pipingdesign.com

## Design Processes

In order to avoid surge pressure damage to piping and pipelines there is one prime requirement. If there is one thing that you, the reader, should gain from this paper it is this premise. This is that you actually need to know that there is likely to be surge in a pipeline system either by measurement or by engineering analysis

"In physical science the first essential step in the direction of learning any subject is to find principles of numerical reckoning and practicable methods for measuring some quality connected with it. I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the state of *Science*, whatever the matter may be."

Lord Kelvin [PLA, 1883-05-03]"

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Thus the first thing to be done is to use the design tools available and analyse a system for potential surge pressures to obtain the "numbers". For if you don't analyse a system you have buried your head in the sand and your knowledge is indeed *meagre*. If the system exists and surges are thought to occur because of the physical evidence then measurement and an analysis is needed. Occurrences such as check valve slam, unstable controls, oscillation in tank levels or pipeline flows and high fatigue maintenance issues are all indicative of surge pressures in your system. You cannot rely on conventional instruments and SCADA systems to be sensitive enough to capture the negative or positive pressure surge events when they occur.

Each piping system is unique and it is impossible to relate one to another and dispense with the engineering required to assess the need for surge analysis. Nor is it feasible to mitigate a surge pressure by employing one of the many devices or processes described in this paper without knowing their effectiveness. They may indeed compound the problem.

## Types of Damage from Surge

Some people advocate the use of the Joukowsky formula to determine the worst case of surge. Unfortunately, although this may provide a high transient number it does not always indicate the highest transient pressure that will occur in a system for all scenarios. In practice this equation is usually only directly applicable to quite simple pipe systems and when rapid collapse of vapour cavities does not occur[1]. In a complex system the pressure transient bounce off boundaries and can combine to produce even greater surges than for a simple valve closure in less than a pipe period. The equation makes no allowance for vacuum events that may result in buckling failure of a pipeline system. There are two categories of damage that arise from surge events. These are:-

- ***catastrophic failure of the pipeline or equipment***
- ***fatigue failure of the pipeline, supports and/or of equipment components***

The consequences of failure are particular to your business.

[1] Prof ARD Thorley Fluid Transients in Pipe Systems Section 1.3 page 17

## *Summary of Devices in a System that Mitigate Surge*

There are many devices that can be used to mitigate transient pressures. However without an *analysis* there cannot be a *design*. The first step is therefore to determine if there is problem of surges in your pipe system that exceeds the design pressure.

The devices that may be considered for mitigation of surges include but are not limited to the following. They are not listed in any particular order of effectiveness or cost. Each is specific to the system being analysed. Each is capable of being modelled in modern software. Each has different effectiveness for catastrophic or repetitive damage type scenarios. Some depend upon pneumatic, hydraulic or electrical power, or fluids, being available to ensure their effectiveness. None should be employed without an analysis of the particular system.

It should also be recognised that any device used to mitigate transient surge pressures or vacuum needs to be maintained. It should be given the same level of attention as a safety relief valve for if the surge mitigation device doesn't perform, when required, then surge pressure events will occur. The devices or process should be fully documented, routinely tested and labelled accordingly.

- Stronger pipework to withstand the pressure surge
- Rerouting piping
- Additional pipe supports
- Change of pipe material to one with a lower modulus (i.e. thermoplastic pipe materials)
- Flow control valve
- Air/Vacuum Release valves
- Intermediate check valves
- Non slam check valves
- Bypass Valves
- Gas accumulators
- Liquid accumulators
- Surge tanks
- Surge shafts
- Surge anticipation valves
- Relief valves
- Bursting discs
- Weak pipe sections
- Increase diameter of pipeline to reduce average velocity
- Variable speed drives
- Soft starters
- Valve closure and opening times
- Increasing the inertia of pumps and motors (i.e. flywheels or by selection)
- Minimising resonance hazards by additional supports
- Investment in more engineering

But just a word from Lord Kelvin to temper the quest for an answer:

***"Large increases in cost with questionable increases in performance can be tolerated only in race horses and fancy women."***

## Stronger Pipework to Withstand Pressure Surges

Pipework can be designed to withstand the damaging effects of pressure surges. This may be necessary where conventional means of mitigating surge pressures cannot be employed such as when handling radioactive, highly corrosive or lethal fluids, where no fluid is allowed to escape.

Increase in pipe wall thickness, flange rating and pipe supports can be designed to prevent catastrophic failure. In increasing the wall thickness of the pipe (if this reduces the internal diameter) or the pipe modulus the celerity will increase and create even higher surge pressures. To prevent an increase in fatigue damage devices such as variable speed drives for pumps and slow closing valves should be considered. Although a more costly method of mitigating transient pressures, once installed higher class pipework does not require further maintenance and testing as other mitigation devices require.

## Rerouting Pipelines

Rerouting of pipelines can avoid a profile that is conducive to column separation and resulting vacuum or high surge pressures. The profile of a pipeline described as *convex downwards* is more likely to be free from column separation. Changing the route can include going around or through an obstacle. The intent is that the hydraulic grade line is always above the pipeline profile. Although a more costly method of mitigating transient pressures, once installed a more desirably routed pipeline does not require further maintenance and testing as other mitigation devices require.

## Additional Pipe Supports

Additional pipe supports allow the movement of pipes arising from pressure transients to be controlled so that an individual support has less likelihood of failing. In addition the natural frequency of the pipework is increased and thus there are fewer tendencies for excessive displacement due to resonance to occur[2].

Additional pipe supports can be provided at concentrated masses as it is at such locations that the most damaging displacements can occur resulting in high local stresses and buckling.

The method of fixing a pipeline changes the celerity of the fluid in the pipework. Most software packages include the selection of the type of fixation.

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[2] Design of Piping Systems MW Kellogg Company Ch. 9 Vibration, Prevention & Control

## Change of Pipe Material to One with Lower Modulus

For a particular pipeline it may be possible to use a thermoplastic or GRP material rather than a ferrous pipe material. This applies to low head pipelines found in the mining, water and wastewater industry where high temperatures do not occur.

The reduced modulus results in a reduced celerity (wavespeed). The extract below demonstrates that modulus is the prime variable in establishing the celerity[3]. K is the bulk modulus of the fluid.

The reduced friction in a plastic material reduces the damping effect of a surge wave and the number of oscillations may actually increase.

The reduced celerity means that the time for a pressure wave to travel to the end of the pipeline and return is increased proportionally. Thus the critical time for closing of valves has to be increased so that they don't act as rapid close valves and create surge phenomenon on themselves.

## Flow Control Valve

Flow control valves can provide a means of changing the hydraulic grade line to reduce the potential for column separation. In a pipeline with varying slopes that may include ascending and descending gradients there is a great potential for column separation. This is particularly so if the HGL is below any of the peaks in the pipeline profile during one or more of the operating scenarios. It is a common solution to provide a flow control valve at the end of the pipeline to ensure that the HGL remains above the profile.

This is also advantageous in water transmission lines as it avoids the potential of negative pressures that may result in contamination of the water. Valves used in this industry are self contained pilot operated piston diaphragm valves. There are a number of manufacturers in Cla-val, Singer, Dorot, Senior Mack, Tyco etc. These valves have the advantage of flexibility in design in that a number of pilot valves can be mounted to enable them to function in a number of modes. The flow control valve can be linked with a float operated pilot to operate as an altitude valve for the receiving reservoir.

## Air/Vacuum Release Valves

The air/vacuum release valves used on pipelines come in many forms of complexity. Many manufacturers have developed the form of valve from the basic *kinetic* air valve developed many years ago. Many of the valves are manufactured to an outdated design that can actually contribute more to a surge event than they relieve.

> *Although in practice the admission of air is not without problems, most of the problems are found during the release of air, sometimes resulting in pressures even higher than if air valves were not installed.*[4]

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3 Introduction to Fluid Mechanics Prof Nakayama & RF Boucher

4 Dynamic performance of Air Valves BHRA Group 2004 International conference on Pressure Surges

Many air valves are described as being of a nominal diameter. This generally only describes the connection size and not the orifice size for the air ingress or air release. These latter criteria have significant bearing on the air valve performance. It should be remembered that the maximum pressure differential for air ingress is atmospheric pressure to full vacuum whereas the similar parameter for air egress is pipeline pressure to atmospheric pressure. The latter can be significantly higher than the former. In addition, the condition of the air may be above sonic velocity in either situation. This gives rise to four equations that may cover the situation occurring at the air valve. Any software needs to be able to determine the condition and apply the correct equation of state.

Ventomat have developed the design of air valve to provide a simple multiple orifice unit. It doesn't have complex linkages or easily deformed ball floats requiring high maintenance. It has proven to be effective in mitigating surge pressures as well as meeting the primary criteria of air elimination and vacuum relief when scouring a pipeline. The Ventomat valve is taller than legacy units. The decision to use these valves needs to be determined early in the design process if it is desired to keep them below ground in a chamber. This may be necessary if the pipeline is in a road reserve or an urban area. Further information on the behaviour of air valves may be found at www.ventomat.com. There are other manufacturers of multiple orifice valves. The design of the air valve should be carefully considered by the designer.

In sewage or other solids bearing service there is a reluctance to use air valves. There are designs for air valves for these services. There is no escaping that maintenance level will be increased if this device is used to mitigate transient pressures in contaminated service.

This type of device cannot be used on liquid hydrocarbon service as the ingress of air may create greater problems than it solves.

## Intermediate Check Valves

An intermediate check valve, in a long pipeline, has the ability of preventing damaging reverse velocity from reaching a pump station. It effectively halves the pressure surge. The difficulty is that such a valve may end up being located in a remote location or in a road reserve. If the need for such a valve is established early in the design process then the pipeline route can be re arranged to suit.

Any intermediate check valve is preferred to be of the non slam variety described below.

## Non Slam Check Valves

The type of check valve used has a great bearing on the pressure transients that can occur in a system. European designers have long recognised this and the use of nozzle type check valves is more common place. In the scheme of things the use of this type of valve is but a small investment in reducing risk and fatigue damage.

Swing check valves are considered by many as unsuitable in high head systems.

> *Simple clapper valves tend to have a very poor response, spring assisted split disc valves, especially with stronger springs, are a little better, whereas nozzle type valves generally have a an excellent response.*[5]

Many facilities exposed to check valve slam with conventional swing check valves have been made silent by the use of the nozzle type check valve. For more details refer www.noreva.de or www.mokveld.com . The nozzle check comes in two types. The single spindle single spring or annulus multiple spring type. Like all items of equipment the designer should take note of the specific design requirements of the equipment. The valve should be installed in a pipeline in accordance with the manufacturer's instructions and the knowledge available from recognised piping and valve design texts.

There have been some instances of horizontal orientated single spring nozzle type valves jamming and users should check with the particular manufacturer as to their experiences. A rare problem with the multiple spring design is that is may jam when a flow is unevenly distributed, for example after a bend. Some models are better than others and the engineer needs to determine this in the technical evaluation.

Jamming of a valve has to do with internal friction of a valve and the applied spring strength, not whether they are multiple spring of not. Mokveld & Noreva check valves are optimised to allow the highest spring strength possible, providing an improved dynamic behaviour but also this will prevent jamming of the valve. Further more the Mokveld & Noreva designs have less friction of moving parts than other designs again eliminating the chance of jamming. The Mokveld & Noreva designs are less prone to failure than other designs on the market. They have replaced many of their competitor's valves, especially in critical applications. Mokveld & Noreva are considered by many, including their competitors, as technology leaders. These manufacturers provide technical information based on flow testing at Delft laboratories. They have characteristics of low pressure loss and non slam action.

The surge analysis needs information such as the *pressure to re open* a closed valve, the *reverse velocity* to close. The latter can be obtained only if the manufacturer has tested the valve. Facilities exist at the Delft Laboratories or Utah State University to test independently. Many manufacturers have not had their valves tested, they rely upon a design copied or licensed from decades previously and the current resources just do not understand the fundamental design of the devices and how they interact with the piping system. Technically professional valve suppliers, such as Noreva & Mokveld, can provide *deceleration versus maximum reverse velocity* data.

There may be other valve suppliers with similarly competent valves and technology and the designer should investigate these fully before deploying there valves. Readers are referred to the work by Prof ARD Thorley[6] for a more complete understanding of the behaviour of check valves and their relationship to transient events.

Difficult applications such as sewage and slurries require specific designs of valves and sometimes compromises in their design and application. In fact automated

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[5] Fluid Transients in Pipeline Systems Prof ARD Thorley ref 1.3.2.4

[6] 1 Fluid transients in Pipeline Systems Ch3.8 ISBN 86058 405 5

isolation valves may replace a check valve in severe applications such as these. The characterised Cv versus % open combined with opening/closing time of these valves then needs to be considered in the analysis.

## Bypass Valves

Bypass valves take the form of a valve in parallel to the pumps. The concept is that on loss of power there is still a reduced flow into the pipeline via this valve. This prevents the column separation occurring immediately downstream of the pump discharge check valve. This type of device is used where the tank being pumped from is above ground and has enough head to drive liquid into the pipeline with a low static head. The second application is where there is a booster pump in the pipeline. The bypass valve opens and thus protects the pipeline when the booster pump fails.

The bypass valve is commonly a reduced size check valve. A fail open actuated valve may also be used. This may be of the pilot actuated cylinder or diaphragm type valves.

The selection of valve size, characteristics and location cannot be guessed. A number of sensitivity analyses are recommended to fully evaluate the effectiveness of these devices. This should include varying flow, heads and pipeline roughness.

## Gas Accumulators

There are two types of gas accumulator used for the mitigation of surge pressures. Firstly there is a pressure vessel with a back up compressor that maintains the volume of gas in the unit to cater for pressure changes. The second is a pressure vessels fitted with an elastomeric bladder with gas one side and the process fluid the other.

The gas accumulator is particularly effective when there is a loss of power situation and a negative pressure wave develops immediately downstream of the pump check valve. The residual pressure in the gas accumulator reduces the deceleration of the liquid column and prevents column separation. The gas accumulator needs to be located close to the boundary element that causes the transient event.

One consideration to be borne in mind with the use of gas accumulators is when pumps are operated in parallel. Should one pump fail then the check valve on that pump is liable to slam closed quickly as the pressure is maintained by the gas accumulator. Consideration should be given to a non slam type check valve that closes very quickly and would thus avoid such phenomenon.

Sizing of gas accumulators can be done manually however this involves some rigorous analysis. Surge analysis software enables the sizing to be undertaken for a system.

One manufacturer dominates the proprietary manufacture of these units. Information can be found at www.olaer.com.au. Other types are available from www.pulsco.com

Gas accumulators are commonly used on the discharge of positive displacement reciprocating pumps. The volume and gas pressure need to be designed and then tested during commissioning.

## Liquid Accumulators

A liquid accumulator is a vessel that has lower elasticity than the pipe itself. The concept is that the vessel will exhibit strain to a higher degree than the pipe and thus mitigate pressure transient. These units are not as effective as a gas accumulator. In general it may be a piece of equipment in the process for another purpose that when modelled does mitigate a surge. One example is a plate type heat exchanger where the plates may deform on the process fluid side. The pressure surge is then transferred to the heat transfer fluid side of the exchanger. If the HT fluid system is an open system with an air release tank then the surge pressures may be mitigated via this secondary system.

Without physical test data of the bulk modulus of a liquid accumulator it is difficult to model accurately in an analysis.

## One Way Surge Tanks

One way surge tanks are principally used on water transmission lines to overcome sub atmospheric pressures. They only function when the local hydraulic grade line falls below the water level in the tank. Under transient conditions the places in the pipeline where this is most likely to occur will be at significant reductions in upward slope and in the vicinity of peaks in the pipeline profile.

They prevent a pipeline collapsing due to buckling from external pressure. The surge tank is suitable sized to fill a cavity formed by vapour column separation. The discharge pipe has to be sized to enable the fluid to enter the pipeline. A check valve is normally fitted to the discharge pipe to prevent positive pressures overflowing the surge tank. To fill the surge tank a pipe from the main transmission line via a float valve feeds the tank.

Surge tanks do not provide protection against positive pressures.

Sufficient time must be allowed in the pipeline for the surge tanks to be filled again after an event. This can be done by slow starting of the pumps under VSD control or by one pump in a pair of pumps running to refill the tank. Ideally the level in the tank should be made available to the operator starting he pumps by telemetry or satellite link.

## Surge Shafts

Surge shafts have been used on low pressure applications. The design of surge shafts is a specialised subject traditional used in the hydroelectric industry. References are given to this design process[7]. A surge shaft is effective in providing protection where a valve or penstock at the end of a pipeline is closed rapidly.

Not all software can adequately model gravity lines feeding a turbine generator. Designers should consider carefully the ability of software to handle this type of application.

[7] Pressure Surges in Pipeline Systems Prof. ARD Thorley 1.3.3.3

## Surge Anticipation Valves

A surge anticipation valve is designed to provide a diversionary flow of fluid in the event of a transient pressure occurring. These valves are low cost and have had some measure of success. They do need a higher degree of engineering and commissioning at site to ensure that they work efficiently. The concept is designed to release energy in a system before damaging pressures can occur.

The device needs to be deployed as close to the point where the transient event is initiated. It may be designed to allow fluid in or out of the system. In the oil pipeline industry very high pressure nitrogen gas operated valves have been used to rapidly open such valves to dissipate energy.

These devices are complex and rely upon a high degree of maintenance to ensure that they work effectively. Control systems need to be backed up by a uninterruptible power supply to ensure that on loss of power they work. Generally remote pumping stations don't have a UPS.

Some manufacturers offer to undertake the surge analysis and to size the valves. A designer needs to ensure that the software is capable of analysis the whole system for a range of scenarios to ensure that the predicted performance is valid. Designers should not see the vendor as a means of reducing their design commitment. Rarely do vendors have any professional indemnity insurance to rely upon.

## Relief Valves

Relief valves come in a variety of designs. A simple conventional spring loaded relief valve is most unlikely to operate sufficiently fast to relieve a pressure wave as it passes the relief valve nozzle.

*To be effective against shock waves a pressure relief valve must be placed as close as practicable to the main pipe which is being protected. If a valve is located on a branch pipe the shock wave will have passed the branch by a distance of about twice the branch \length before the reflected wave from the relief valve gets back to the pipe junction as a reduced pressure wave.*[8].

Specialised relief valves have been designed for use in the water industry. They are termed a Neyrpic valve. They are direct acting valve designed to operate in milliseconds. It is a simple spring loaded disc with no guides that require maintenance to ensure that the valve operates.

The use of pressure relief valves comes under the codes and standards listed in Appendix I.

## Bursting Discs

The bursting disc is another form of relief device. The drawbacks from the use of a bursting disc are similar to the relief valve. If deployed when they have served their purpose they have to be replaced before the process can be restarted.

[8] Waterhammer T. Webb & BW Gould Water hammer Mitigation

The designer should bear in mind that a bursting disc pressure rating is provided by manufacturing a quantity and testing some of them. By statistical means then assign a burst pressure to the balance that are to be used to protect a pipeline. Some design factor has to be employed to ensure that protection at the design pressure will occur.

Metal bursting discs have been known to suffer from fatigue and fail prematurely reducing the availability of an asset.

The use of bursting discs comes under the codes and standards listed in Appendix I.

## Weak Pipe Sections

It has been suggested that using a combination of ferrous pipeline materials with a lower modulus thermoplastic material provides a weak section that will mitigate a pressure surge. With the correct engineering analysis of all the scenarios this has merit. A high pressure section of the pipeline may by designed in ductile iron with a PE or ABS pipe used for the low pressure section. This has been successfully employed.

In chemical dosing lines some sections of plasticised PVC hose have been used to remove the pulsations from a positive displacement dosing pump.

## Increased Diameter of Pipeline

If it is possible to increase the diameter of the pipeline the immediate effect is to reduce the surge pressures. This occurs as the velocity is reduced. When the fluid is brought to rest the change in momentum is reduced in direct proportion to the maximum velocity.

The downside is that the increased pipeline size reduces the friction so the damping of any pressure fluctuations is reduced and the transient may also considerably longer. This adds to the fatigue loading of components in the system.

The other consideration is the increased cost of the pipe versus the reduced energy costs over the life of the asset. It must be remembered that the pump will no doubt have a smaller motor; making the VSD and motor starters smaller so there will be some capital expenditure saving there.

## Variable Speed Drives

Variable speed drives provide a reliable means of prevention of damage from surge events. They only provide this when there is power so for a *loss of power* event they are of no use. A *loss of power* event can result in the highest positive and negative pressures in a system. In most applications this event is rare.

The VSD provides the best method of reducing fatigue damage to pipeline components. Check valve slam is avoided as the liquid column decelerates slowly. The VSD allows the pump speed to increase slowly to achieve slow line filling and thus the air can be removed without damaging the pipeline. They also provides flexibility of operation for a process where flows can be increased for future needs without changing the equipment.

The use of VSDs may require a more extensive air conditioning system in a switch room to remove the heat generated by the device. The efficiency of a VSD may be 95-98% depending upon its design. The 2-5% inefficiency is transmitted as heat energy into the switchroom.

## Soft Starters

Soft starters' primary purpose is to reduce the electrical load on the power supply to a facility. They are widely deployed in many pumping stations for this purpose particularly where the pump station is at the end of a long power transmission line.

Soft starters are described as a poor *mans VSD*. They have some but not all of the features of a VSD. They are able to control ramp speed up and down to some extent. Therefore they do provide benefits in reducing surge in some applications. This is not a universal panacea. There have been instances where a system still sees surge pressures and the soft starters have had to be replaced with VSD s or other mitigation measures employed.

## Valve Opening and Closing Times

A common form of surge pressure initiation has been the rapid closing of a valve. The worst valves for this event are the pneumatically operated butterfly, gate, globe, knife-gate or sluice valve. The worst valves include manually operated quarter turn valve butterfly, ball and plug valves without a gearbox for these can be rapidly closed or opened.

If the time of closure of a valve is less than the time a pressure wave to travel from its point of initiation to the end of a pipeline and return then the valve is described as having a *rapid closure.* This results in the maximum head predicted by the Joukowsky equation or column separation.

The closure time may however be dictated by some other process requirement such as an Emergency Shutdown Valve (ESD).

Extending the closure times is often restricted to short pipelines. Some facilities employ the two stage closing process whereby the valve is closed to a 15-20% open position rapidly and then the last closure is over an extended period. Similarly the valve opening is a two stage process. In high pressure systems dual valves in parallel of different sizes are used with the smallest opening first, it closes whilst the bigger valve closes and then reopens to obtain maximum flow rates.

Butterfly valves are a valve to avoid this type of control. Their performance is not suited to a wide range. If butterfly valves are to be used then multiple varying sizes are suggested.

Where a process is complex and a number of valves are required to be opened and closed at different times this leads to a great number of computer runs to determine the sensitivity of a system.

## Increase of the Moment of Inertia of Pumps

A parameter used in the surge analysis of a pump system is the moment of inertia (MOI) of the combined pump, fluid and motor rotating elements. Four pole motor driven pumps generally have a higher MOI than an equivalent two pole motor driven pump.. But two pole speed pumps are more economic as far as a contractor building a facility is concerned. There are also added benefits with 2 pole motor driven pumps to the end user in that the cost of replacement components is lower than for 4 pole pumps as they are generally smaller. Sometimes the pump is more efficient than its larger slow running counterpart. The downside is that the faster running pump is unlikely to last as long as it's slower running counterpart. Four pole speed pumps are preferred for infrastructure assets but even so modern designs have reduced the MOI of units as manufacturers have optimised pump and motor designs with the use of FEA and other design tools.

One method of mitigating pressure transients caused by pumps is to use flywheels to increase the MOI. This appears to be contrary to saving money by using a smaller frame pump then spending more adding *metal* in a flywheel to meet a surge pressure mitigation need. Flywheels in pumping applications are rare. Flywheel will increase the starting current of a pump and thus there will be an increase in cost of motor starters, soft starters or VSDs.

Positive displacement pumps are a special case. This type of pump has a tendency to stop almost instantaneously on loss of power. There is little that can be done to improve this fact and thus other devices need to be employed. These include design and installation of the other devices and processes described in this paper.

## Minimising Resonance Hazards by Additional Supports

When dynamic loads are applied to piping systems the system may vibrate. If the forcing frequency resonates with the natural frequency of the pipework then the deflections may cause damage to the system. As fluids oscillate as a result of pressure surges this may occur. The designer needs to establish the natural frequency of the piping and that resulting from surge events. Software allows the input of forcing functions along with modal analysis to determine the interaction of these phenomena.

The use of additional pipe supports can change the natural frequency of a piping system to overcome the problem of resonant vibrations.

## Investment in Engineering

The designer should consider that many pipelines are designed for a fifty year life. The surface roughness of the pipeline defined in many codes takes into account the build up of slimes, corrosion and other deleterious effects. The worst case scenarios are used for pump and motor sizing. When it comes to commissioning the pipeline is new and friction is much reduced. So the system curve falls on a different point of the pump HQ curve. Add to that the conservatism built into the heat exchanger (clean not dirty), pump & valve performance prediction and the flow rate could be 20-25% greater than design.

The pipe materials used have tolerances that are quite wide. In particular thermoplastic pipe and cement lining allow a degree of latitude to the designer. If an analysis was made using nominal wall and lining thicknesses alone then the predictions could be in error.

That said to undertake an analysis of a system with all manner of variables individually taken into account would result in a phenomenal engineering cost. The only efficient way of looking at the worst cases is to use modern software.

The designer may mitigate the risks involved in having to provide post commissioning surge mitigation devices. This is done by allowing for the following low cost items in the initial design, fabrication and construction:-

- a pair of flanges for an intermediate check valve
- a flange tee for an air valve(s)
- valved nozzles to fit a bypass check valve around a pump
- a nozzle for surge tower or gas accumulator
- nozzles for a bursting disc, relief or surge anticipation valve
- a switchroom sized to house VSDs and increased air conditioning system

The other benefit is that if the pipeline is upgraded in the future and surge protection is needed for the increased flows it becomes easier to modify the systems.

The consequences & risks of a surge event can perhaps be avoided by an increased level of engineering at the design stage. The Codes and Standards require that level of engineering. Is your project undertaking the engineering using the specialist expertise necessary to make informed decisions? It has been said of engineering projects that:-

- a dollar spent at concept stage is worth ten dollars at design stage
- one hundred dollars at procurement
- one thousand dollars at fabrication
- ten thousand dollars during construction and
- one hundred thousand dollars during commissioning.

**Perhaps it will be one million dollars once the lawyers are involved!!!!!!!!!**

## *National Codes and Standards*

Many National Codes and Standards have requirements to design piping systems to take account of the effects of occasional loads such as pressure transients in systems. This not only concerns positive pressures but also negative pressures. Full vacuum can occur when there is column separation in a pipeline. This commonly occurs when there is a loss of power or rapid closure of an upstream valve. Thin wall ferrous and low stiffness thermoplastic pipe may be subjected to the occurrence of buckling due to vacuum. Buckling may be more likely if the pipe has become oval because of the installation techniques.

Codes are generally enshrined in law and are mandatory whereas standards are voluntary unless referred to in a government Act or included in a contract.

***Appendix 1,*** attached, lists a number of National Codes, Standards and Industry references where specific requirements to consider surge are provided. The list can be augmented by those documents that apply in your country or industry.

***This paper has been authored by***
***Geoffrey D Stone F I E Aust CP Eng; F I Mech E C.Eng***
***He has worked as an independent hydraulics and piping engineer in Australia, SE Asia and the Middle East for over thirty years.***

## *Disclaimer*

This document has been prepared as a service to industry. The information in this document is offered in good faith and is believed to be accurate at the time of its preparation but is offered without any warranty, expressed or implied, including warranties of merchantability and fitness for purpose. Any reference to a proprietary product should not be construed as an endorsement by the author or his employer, which does not endorse the proprietary products or processes of any manufacturer.

Pressure piping should be designed by suitably trained and qualified engineers with the experience to interpret the data provided in the referenced Codes, Standards and texts.

## CAUTION

*"AFT Impulse is a sophisticated waterhammer analysis and surge transient modelling program designed for qualified engineers with experience in waterhammer analysis and should not be used by untrained individuals."*
**Trey Walters, President Applied Flow Technology**.

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# *Appendix 1 Reference National and Industry Codes*

## Standards & Codes

A particular industry may use other international standards for the design of their piping systems. These will require that occasional loads, surges or hydraulic transients are taken into account in designing the systems. Common standards used in Australia and New Zealand are listed below and all require the designer take into account occasional unsustained loads arising from surge events:

## Australian Standards

| | |
|---|---|
| **Pressure Vessel Code** | **AS 1210** |
| **Arc Welded Steel Pipe** | **AS 1579** |
| **Submarine Pipeline Code** | **AS 1958** |
| **Installation of UPVC** | **AS 2032** |
| **Installation of PE** | **AS 2033** |
| **Buried Flexible Pipelines Design** | **AS 2566** |
| **Gas & Liquid Pipeline Code** | **AS 2885** |
| **GRP Pipes for Water & Sewerage** | **AS 3571** |
| **Installation of ABS Pipes** | **AS 3690** |
| **Pressure Piping Code** | **AS 4041** |

## International Standards

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|---|---|
| **Power Piping** | **ASME B31.1** |
| **Process Piping** | **ASME B31.3** |
| **Pipeline Transportation Systems for Hydrocarbons and other Liquids** | **ASME B31.4** |
| **Refrigeration and Heat Transfer Components** | **ASME B31.5** |
| **Building Services Piping** | **ASME B31.9** |
| **Slurry Transportation Piping Systems** | **ASME B31.11** |
| **Glass-reinforced plastics (GRP) piping** | **ISO 14692-3** |
| **Design & Construction of GRP Pipes** | **BS 7159** |
| **AWWA Fibreglass Pipe** | **ANSI/AWWA C950** |

## Australian Industry Body Standards

A number of industry bodies have developed specific standards to provide conformity throughout Australia & New Zealand The industry body may represent users such as Water Services Association of Australia (WSAA) or manufacturers such as the Plastic Industry Pipe Association (PIPA).

**WSA 01 Polyethylene Pipeline Code**
**WSA 02 Sewerage Code of Australia**
**WSA 03 Water Supply Code**
**WSA 04 Sewage Pumping Stations**

Readers in the water and wastewater industry are encouraged to support WSAA and download the above documents and others from www.wsaa.asn.au

**POP010A:Part 1 Polyethylene Pressure Pipes Design for Dynamic Stresses**
POP10A refers to the need to design for surge. For additional information refer to www.pipa.com.au