Are You at Risk from Not Considering the Potential for Surges in a Piping System?

This article raises a number of issues in respect of the risks you may be exposed to from the requirements to consider the pressure transients in a piping system design. The risks not only relate to physical damage but also the consequential risks that arise from such damage whether it is contractual, branding or loss of use.

Piping systems are designed in Australia and overseas to a number of National Codes and Standards. In addition to this there are industry bodies that publish design guides and codes that are referred to in contract documents. These require that design for surge are taken into account to determine the loads and stresses in a piping system.

This paper only addresses surge events from a liquid pressure transient. Events arising from condensate in steam or gas lines are not covered here. These events may be even more catastrophic as the velocities of the liquid column are much higher than in a liquid system.

If nothing, read the section on Contract Requirements and consider the risks you run by being ignorant of this engineering topic.

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Revisions
8th June 2005 Section on Check valves General Revision
25th August 2005 General Edits

National Codes and Standards

Many National Codes and Standards have requirements to design piping systems to take into account 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.

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 occurs[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 that a pipe period. The equation makes no allowance for vacuum events that may result in buckling failure.

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 and/or of equipment components***

These are described in more detail below together with some of their consequences.

Catastrophic Failure of a Pipeline

Pipelines have been known to fail catastrophically as a result of surge events. The failure may take the form of a pipe burst or a pipeline collapse from buckling. What are the consequences of a pipeline failure:-

- Delay to completion of the project
- Plant and equipment non availability to the process and thus loss of earnings
- Environmental damage
- Personal injury
- Loss of reputation and branding
- Loss of future work from the client

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

- Damage to other properties, injuries to the public
- Damage to the end user's reputation in the eyes of the broader community
- Litigation with the necessary allocation of valuable resources away from their primary duties
- Increased insurance premiums

Fatigue Damage to Pipelines and Equipment

Pipelines

From the requirements in the Codes and Standards listed it can be seen that the phenomenon of fatigue is recognised. The derating of pipeline materials occurs because of the fatigue that occurs. To overcome the potential of fatigue failure increased pipe wall thickness is required to reduce the stress level in the pipe wall. Historically SN Curves have been used to evaluate the fatigue resistance of pipe materials. Certainly, for thermoplastic materials, the newer science of fracture mechanics FEA is being used to determine the design life of materials.

Pipeline accessories may succumb to fatigue damage. These include leaking gaskets, valve body, seal or gasket failure, instrument failure or pipe support failure.

Equipment

Equipment that may be damaged is specific to a particular pipeline or process facility. The consequences arising from such damage is also specific. Below are a few examples. Those involved in a project should undertake a risk review or HAZOPS and identify these matters and rank the consequences. No doubt the end user will place different priorities on fatigue damage to that of the contractor. Whatever the outcome both contractor and end user must be part of such an analysis and risk profiling.

Damage to equipment may mean that a process is offline whilst replacement equipment is installed. The on-costs can be many times the primary Capex of the equipment alone.

Pumps

Pumps can suffer damage to the seals, bearings, impeller, shaft and casing from surge events. In today's world of high speed small frame pumps the relatively small nozzles are particularly vulnerable if the piping is not correctly supported or isolated.

Seals are damaged as a negative pressure may lift the seal face and allow solids to enter. This will lead to wear and consequential leaks.

Cast iron bodied pumps can fail because of the stress reversals in a fatigue situation. Cast iron is particularly weak in tension.

A surge event may create vortexing that results in loss of prime to a pump system. If only manual bleed facilities are fitted this could shut down a process plant.

Valves

Valves can be damaged by fatigue such their seats will allow fluid to pass and thus not isolate as designed. Gland seals are likely to leak requiring the retightening of the gland or complete re packing.

Control valves may be susceptible to loss of control during a surge event. Control valves have parts that are more likely to be damaged. Such items as positioners or other electronic components are vulnerable.

Check valve seats may be damaged and thus leak. This results in a waste of energy in duty/standby pump arrangements as fluid is recirculated. Shafts and pins have been known to fail due to fatigue. There have also been incidents of the flaps in a dual flap check valve failing completely and lodging is some other process equipment causing blockages.

Air release/ vacuum valves usually have small components or floats that can be damaged by pressures in excess of design or severe vibration resulting from surges

Relief valves may discharge as a result of a surge event. If this occurs frequently the seat may fail from fatigue

If the valve is buried it becomes a major exercise to replace.

Pipe Supports

The vibration resulting from a series of surge events can cause the pipe support to damage the external surface of the pipe material and result in a leak. If the leak is in a difficult access position the repairs become costly and time consuming.

Pipe supports secured to concrete or steel structures can fail at the fasteners as a result of fatigue. The repetitious loading can result in fasteners loosening or failing.

Concentrated masses such as valves may be excited by surge events and cause damage to the piping material. Such items should be supported locally to prevent such occurrences.

Consequences of Fatigue Damage

The consequences of such damage in addition to those listed above are:-

- Emergency call out resources
- Alternate supply lines
- Increased maintenance costs
- Increased investment in maintenance resources
- Complaints procedures
- Standby equipment
- Increased level of spares holding
- Possible special freight arrangements for remote sites
- Increased insurance premiums
- OH&S and industrial relations problems

There are different and additional requirements in this instance because by its nature fatigue damage may occur over a longer timeframe.

Significant Devices in a System that Contribute to Surge

Pumps

A parameter used in the surge analysis of a pump system is the moment of inertia (MOI) of the pump, fluid and motor rotating elements. With the use of 2 pole speed pumps comes low MOI. Four pole speed pumps are preferred but even so modern designs have reduced the MOI of units as manufacturers have optimised 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, and hence retard the deceleration of the rotating assembly.

Positive displacement pumps are a special case. This type of pump has a tendency to stop almost instantaneously unless fitted with a variable speed drive. In any event a VSD will not work on loss of power. Soft starters are sometimes used to provide dynamic control however they tend to be largely ineffectual in such applications.

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.

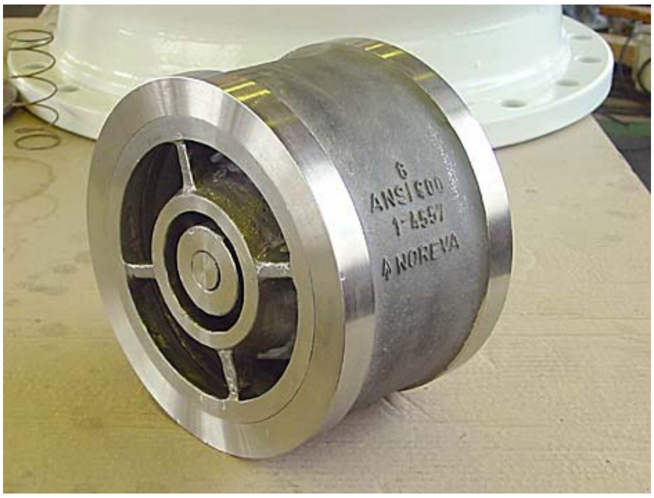
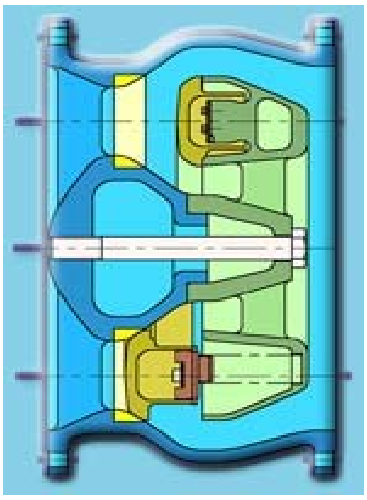
Swing check valves are considered by many as unsuitable in high head systems.

> *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.*[2]

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 with the knowledge available from recognised piping and valve design texts.

Below illustrates a short pattern type non slam valve.

2 Fluid Transients in Pipeline Systems Prof ARD Thorley ref 1.3.2.4

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 it 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 springs 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 the Utah State University to conduct tests independently. Many manufacturers have not had their valves tested, they rely upon a design copied or licensed from decades ago 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 their valves. Readers are referred to the work by Prof ARD Thorley[3] 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 that are sometimes compromised in their design and application. In fact automated

[3] 1 Fluid transients in Pipeline Systems Ch3.8 ISBN 86058 405 5

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

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]

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. This latter criteria has significant bearing on 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 describe the situation occurring at the air valve. Any software needs to be able to determine the condition and apply the correct equation of state.

Further information on the behaviour of air valves may be found at www.ventomat.com.

Why Don't Engineers Undertake Surge Analysis?

You may well ask why engineers don't carry out a waterhammer analysis. Could it be that:-

- There is difficulty in undertaking the calculations using the graphical techniques of yesteryear or modern software of today?
- You don't have the software and these specialist tools are not easy to obtain funding approval for in a large company? Employ a specialist who does!
- It is not understood whether it is an art or a science? Need to increase your knowledge?
- It doesn't really matter as things aren't noticed until they go wrong and because it is complex you can blame someone else? How courageous!
- Fear of the unknown and you were not taught the subject at university? Ignorance is no defence!
- Failures don't appear to be frequent, but consider that most events are buried in confidentiality agreements following litigation.

This paper is aimed at raising the profile of this technology in the minds of managers, operators, designers, installers and public authorities.

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

We live in a risk adverse society. Rest assured someone will not only be looking for someone to blame but someone with deep pockets to pay!

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.

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 power or fluids being available to ensure their effectiveness. None should be employed without an analysis of the system.

- Stronger pipes
- Rerouting piping
- More supports
- Change of pipe material to one with a lower modulus
- Air valves
- Intermediate check valves
- Non slam check valves
- Dampened retarded check valves
- Gas accumulators
- Liquid accumulators
- Surge tanks
- Surge shafts
- Surge anticipation valves
- Relief valves
- Bursting discs
- Weak pipe sections
- Variable speed drives
- Soft starters
- Valve closure and opening times
- Increasing the inertia of pumps and motors
- Minimising resonance hazards by additional supports

Available Software

Before reference is made to the available software any organisation needs to consider who is conducting the analysis. The work involved in modelling a particular system requires a high degree of knowledge of the software to be used and the technology of surge analysis. It is not just plugging numbers into a software model and getting the answers.

The pressure transient magnitudes derived in an analysis serve only as a pointer to the type of pressure event that may occur. End users should recognise that a number of assumptions have to be made in any model. The rigorous analysis of the assumptions can only be carried out by varying one parameter at a time and reviewing the sensitivity of the model. When a system is particularly sensitive to a parameter it is usual to adopt the more conservative result. Alternatively, the data can be investigated and more accurate information may be used to gain a more representative answer. Both methods are legitimate.

Engineers have the choice of a number of software packages each with their own merits, ease of use and licence fees. The software may have been developed for a particular industry or may be more generalised and thus flexible in its application. In evaluating the software it is imperative that the product support provided is carefully reviewed. As the applications are complex it helps if the support comes from an engineering slant rather than one that is more IT based.

In evaluating the software it is of benefit to use the guide found at the following website http://www.civil.ist.utl.pt/~hr/PS-HP.pdf .

The following software references are given, in no particular order. When investigating the available software it may be worthwhile selecting software that is used by colleagues or sister/client companies so that reference can be made to others in your industry. In addition if you intend to develop skills in house you may need to initially use the services of an experienced analyst to verify your designs or provide an independent evaluation. Therefore investment in the same software has merit. No attempt is made to rank the software listed below.

(i) *AFT's Impulse www.aft.com
(ii) *Hytran www.hytran.com
(iii) *Pipenet www.pipenet.com
(iv) Hammer www.haestad.com
(v) Watham (A DOS based program with a large user base in Australia)
(vi) Flowmaster www.flowmaster.com
(vii) Arts http://www.aquavarra.ie/arts/watham.html
(viii) Surge 2000 http://www.mpassociates.gr/software/environment/surge.html
(ix) Wanda http://www.wldelft.nl/soft/wanda/mods/transient/

* This software is available from www.accutech2000.com.au .

There are probably others on the market however the above are those that came from a simple search of the internet. The author of this paper has used *AFT's Impulse* for many years.

It should be recognised that there is great investment in the technology and the software. Many have invested in such software and trained their engineers only to find the software rarely used and when it comes time to deploy it there is a re-familiarisation period. The other problem has been that the *surge analyst* ups and joins your competition. From the engineer's perspective in a large organisation he, or she, may become too valuable in the role as the *surge analyst* and be overlooked for promotion to more senior roles. Even if promoted they may be expected to come back to do more *technical* than *managerial* tasks, that is if they are available during the project's timeframe.

Investment in Engineering

The above consequences 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
- one hundred thousand dollars during construction and

- one million dollars during commissioning.

Perhaps it will be ten million dollars once the lawyers are involved

Contract Requirements

Many contract documents and specifications will list all or some of the above documents. Then there will be a general requirement that the contractor should comply with the provisions of the referenced Codes or Standards. Those preparing the specifications may or may not have detailed knowledge of the provisions of the documents and thus will not understand the ramifications. They generally list all standards that have a bearing on a design without specific reference to clauses in detail. Those tendering against the Specification may not fully understand the responsibility associated with these documents.

In respect of the requirements of a surge analysis there are obviously references in the documents that can be invoked to ensure that the contractor undertakes such a study.

A risk exists that the contractor has not allowed to undertake a study of the piping system in their estimate, let alone, the cost of any surge mitigation devices. Suppose the only solution to the transient pressures arising from an event was a bladder type surge vessel. These are imported devices with lead times of twenty (20) to twenty six (26) weeks. They are registered pressure vessels requiring statutory approval. Since they come from overseas they are invariably designed to an ASME or European Code thus making the approval and certification process more complex.

Can the Contractor afford the impost of this extra time on the project?

What if the contractor proceeded without a surge analysis and there was a problem of check valve slam, failed pump seals or bearings, a broken pipeline with environmental damage or some other catastrophe?

Who bears the risk under the contract of not complying with the provisions set out in the Codes and Standards? Invariably the end user will argue that it is the contractor. The contractor is expected to be a specialist in the industry to which the relevant standards are used. Their own marketing people would have extolled the virtues of their organisation along with their professionalism. Even if they can argue their way around the contract they could still be exposed under the Trade Practices Act. Contractors should refer to their own legal advisors to determine their exposure under a particular contract specification and as to their responsibilities in the matter of surge analysis and its mitigation should it prove to be a problem.

What Can You Do to Protect Yourself?

Having explored the topic what can you do to provide protection?

1. Read the specification and referenced standards and understand what is required under the Contract
2. Ensure that you have available the necessary technical resources to meet your obligations either in house or external specialised services

3. Ensure that the designer has the requirements of the standards, codes or industry requirements embodied in their Design Plan or Quality Assurance Program
4. Undertake a risk management strategy with all stakeholders using the reference AS 4360 as a tool to document the investigation
5. Analyse the system to determine if mitigation is necessary for the prevention of catastrophic or long term damage, including any future expansions/augmentation
6. Design & install appropriate mitigation devices
7. Verify the design by testing using a lower risk set of conditions that have been modelled.
8. Maintain the system mitigation devices
9. Document the devices installed to protect the system. The surge mitigation device is an important as a relief valve in respect of protecting an asset from over pressure.

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Disclaimer

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Appendix 1 Reference National and Industry Codes

The following standards, codes and industry publications can be augmented by those from your country or industry.

AS 4041 Pressure Piping Code

Clauses 3.5 and 3.9.5 refer to occasional loads such as surge.

AS 2566.1 Buried flexible pipelines Part 1: Structural design

This standard requires that buried flexible pipelines be designed for buckling. Part of the design requires that the external forces such as vacuum be taken into account. Vacuum will occur in pipelines where column separation occurs as a result of a loss of power to a pump or closure of an upstream valve on a gravity line. The level of vacuum occurring can only be determined by analysis of the system behaviour.

AS 1579 Arc Welded Steel Pipes for Water and Waste Water

AS 1579 clause 2.1 refers.

AS 3571 Glass filament reinforced thermosetting plastics (GRP) pipes—Polyester based—Water supply, sewerage and drainage applications

AS 3571 clause C2 refers to urge in determining the *Service Condition*.

AS 2885-1 Pipelines—Gas and liquid petroleum Part 1: Design and Construction

AS 2885.1 clause 4.3.6.2 refers to the need to allow for occasional loads such as surge.

AS 3690 Installation of ABS pipe systems

AS 3690 clause 2.4.4 refers to the effects of waterhammer.

AS 2032 Installation of UPVC pipe systems

AS 2032 clause 4.1.5 refers to waterhammer and surge effects

AS 2033 Installation of polyethylene pipe systems

AS 2033 clause 4.1.5 refers to waterhammer and surge effects.

ISO 14692-3 Petroleum and natural gas industries — Glass-reinforced plastics (GRP) piping — Part 3: System design

ISO 14692-3 clause 6.5 refers to waterhammer and clause A6 refers to buckling criteria that may be brought about by vacuum.

AS 1958 Submarine Pipelines

AS 1958 clause 3.19.1 refers to the need to consider surge in the design.

Other Standards

A particular industry may use other international standards for the design of their piping systems. These will invariably require that occasional loads, surges or hydraulic transients are taken into account in designing the systems.

Some other common standards are listed below that all require the designer take into account occasional unsustained loads such as surge:

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**

Industry Body Standards

A number of industry bodies have developed specific standards to provide conformity throughout Australia. These Codes and Standards are produced to provide guidance where a national standard does not exist. The industry body may represent users such as Water Services Association of Australia (WSAA) or manufacturers such as Plastic Industry Pipe Association (PIPA).

WSA 01 Polyethylene Pipeline Code 2001

WSA 01 clauses 2.4.4, 2.6.3, 2.10.3, 3.1, 3.4.2 & 3.5 refer to the various aspects of surge. Designers of these assets should be well aware of the requirements.

WSA 02 Sewerage Code of Australia

This document defers to WSA 03 Water Supply Code for requirements for pressure piping. Designers of these assets should be well aware of the requirements.

WSA 03 Water Supply Code

This document has too many references (more than twenty) to surge to list here. Designers of these assets should be well aware of the requirements.

WSA 04 Sewage Pumping Stations

This document has too many references (more than twenty) to surge to list here. Designers of these assets should be well aware of the requirements.

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