WHITE PAPER

Eliminating Water Hammer

How to protect pumping systems from damaging pressure surges

BENSHAW
Applied Motor Controls

The basics of water hammer

The term “water hammer” is used to describe pressure surges within a piping system. There are a range of mechanisms and triggers for water hammer, and having a clear understanding of what is causing the phenomenon in a particular installation is key to identifying the right solution.

THE SCIENCE IN A NUTSHELL

The mechanics of water hammer are actually quite simple.

One cause of water hammer is when the leading edge of a fluid column in a pumping system encounters a blockage, a common example being a suddenly closed valve. When this happens the flow of the water at the leading edge is instantly halted, but the fluid behind is still moving and starts to compress.

Because of this compression, a small amount of fluid continues to enter the pipework even though the water at the leading edge has stopped moving.

The kinetic energy of the water in the system is converted to pressure energy as the water compresses. Logically, this pressure energy created cannot continue past the blockage in the system. Instead, the pressure wave generated by the compression of water in the pipe will travel back upstream.

The other primary cause of water hammer is water column separation and closure. This occurs when the column of liquid water within a piping system is separated and subsequently closes again, generating a damaging shockwave.

Regardless of the cause, the increased pressure generated by the water hammer phenomenon can cause significant damage to any system not designed to accommodate such stresses, bursting pipes, damaging valves, and more.

This can occur in a two phase system – one in which water changes state and can exist as both a liquid and a vapour in the same confined volume. This 'phase change' (ie liquid water to water vapour) can take place whenever the pressure in a pipeline is reduced to that of the vapour pressure of the water[1].

These causes have a number of triggers. Pump starts and stops can cause water hammer through both mechanisms. A rapid change in flow and system pressure during starting or stopping can cause sudden closure of check valves, while changes in the direction of flow can induce water column separation.

[1] Joe Evans, Ph.D, Waterhammer - - Part 2 – Causes & Variables
http://www.pumped101.com/

CALCULATING THE BIG BANG

The damaging potential of water hammer can be calculated using the formula $P_{(additional)} = aV/2.31g$ where:

- P = the additional pressure created in the system
- a = 4860ft/s (the speed of the pressure wave)
- V = the velocity of the flowing water in the pipe (ft/s)
- g = the universal gravitational constant (approximately 32ft/s^2)

Example: Water is being pumped at a flow rate of 10 ft/s. A valve in the pipeline is closed (one of the primary causes of water hammer) instantaneously, stopping the flow of water in the system.

Using the formula $P_{(additional)} = aV/2.31g$, it is evident that an additional 657 PSI of pressure will be created within the pipe. If the system is not designed to cope with this severe damage is likely to occur to the valves, pipework, and/or pump.

The solutions

Solving the water hammer problem requires either mitigating its effects or preventing its occurrence altogether. To this end, there are a number of solutions to consider when designing a pumping system.

Pressure tanks, surge chambers or similar accumulators can all be used to absorb pressure surges and are useful tools in the fight against water hammer. That said, preventing the pressure surges in the first place is often a better strategy.

CONTROLLING VALVE CLOSURE TIME (PREVENTION)

As discussed earlier, sudden closure of a valve is one of the primary causes of water hammer. Of the many variables at play within a pumping system, valve closure time significantly impacts the likelihood of damaging water hammer occurring, yet is a factor over which we have a level of direct control.

The following equation shows the relationship between valve closure time and the magnitude of the water hammer pressure surge:

$P = 0.07 (VL / t)$

Where:

- t = the valve closing time in seconds
- L = the length of the pipe between the barriers in feet
- V = the flow velocity in ft/s

The additional pressure generated by the closure of a valve is inversely proportional to the valve closure time. That is, the more slowly the valve is closed, the less significant the increase in pressure will be. Furthermore, it is evident that by careful consideration of the variables within our control (closure time and flow velocity), incidence and intensity of water hammer can be notably reduced.

Controlled valve closure can be achieved manually or by use of motorised valves.

ELECTRONIC SPEED CONTROL DURING PUMP STARTING AND STOPPING (PREVENTION)

Electronic motor control devices such as soft starters and variable speed drives can be used to control the speed of the pump during starting and stopping. This allows for a more gradual increase or decrease in pump speed (and hence of flow and head / pressure) to prevent water column separation, flow reversal and sudden check valve closure.

Controlled starting and stopping of pumps also offers other advantages, including reducing mechanical stresses on the system and electrical supply caused by DOL / ATL / electromechanical starting. This results in reduced maintenance and extended life. Furthermore, soft starters and VSDs can provide a range of advanced motor and system protection functions as well as monitoring and control options.

For example:

- pump/motor overload protection to detect burst pipes
- undercurrent protection to detect blocked pipes
- phase rotation protection to prevent reverse rotation of the pump
- phase loss protection to prevent damage from power disturbances
- instantaneous overcurrent protection to prevent pump damage due to debris
- automatic timers and schedulers for control of operation
- operational logs and recording

WHAT YOU NEED TO KNOW WHEN USING ELECTRONIC SPEED CONTROL TO PREVENT WATER HAMMER

The effectiveness of electronic speed control in the reduction of water hammer is determined not only by the type of technology within the soft starter or variable speed drive (which will be discussed later) but also by the pump and system curves.

SYSTEM CURVES

The system curve displays the relationship between flow rate and pressure within the system. It is made up of two components, static head and dynamic head (Figure 1).

Flat system curves are more sensitive to changes in speed. A small change in speed will create a big change in flow. This means speed control must be precisely managed to prevent water hammer.

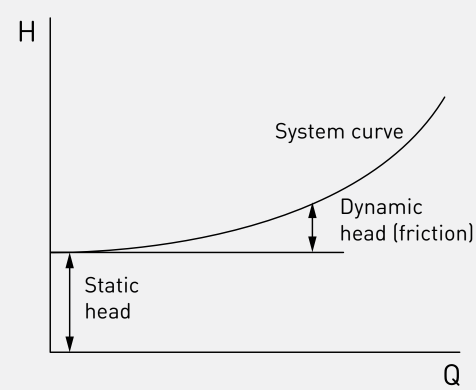

Figure 1: System curve

PUMP CURVES

Pump characteristics vary widely, resulting in a range of different possible pump performance curves. With a 'steep curve' pump, a large change in pressure produces a small change in flow. Conversely, with a 'flat curve' pump a small change in pressure will result in a large change in flow (Figure 2).

To help abate water hammer in a system, choose a steep curve pump wherever possible. The relationship between pressure and flow rate for such pumps makes precise control of the flow rate via control of pump speed much easier.

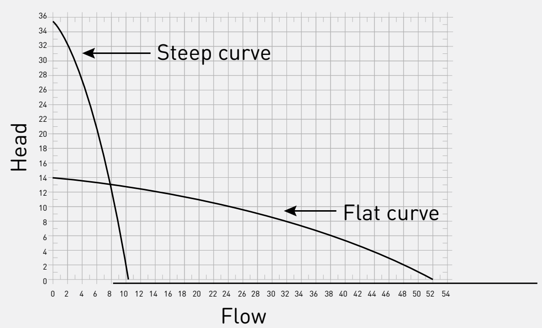

Figure 2: Pump curves

FIXED SPEED OR VARIABLE SPEED CONTROL?

Once electronic speed control has been decided upon as a solution, next comes the choice between use of a soft starter or a VSD. Both are able to control the acceleration and deceleration of the motor/pump and thus mitigate water hammer, so which is the best choice? This will depend on the system characteristics.

Soft starters run the system at full (fixed) speed during operation, controlling the speed during pump starting and stopping only. Once the system reaches full speed, the soft starter is typically bypassed and operates with very high efficiency (losses of less than 0.1%) thus reducing running costs. Soft starters also come at a lower cost than variable speed drives. Additionally, harmonic generation onto the electrical supply is not an issue with soft starters meaning they do not necessitate the use of costly filters.

On the other hand, VSDs control pump speed during operation as well as during start and stop. This additional ability to control 'run time' speed comes at a cost. VSDs have a considerably higher capital cost than soft starters, often require harmonic filters (costly devices that prevent harmonic distortion on the electrical supply), and typically produce energy losses of 4-6%, adding to the lifetime cost of the system.

That said, in some pumping systems the ability to control flow during operation will produce other system efficiencies that outweigh the higher capital and running costs. Unless such system efficiencies are proven to exist then soft starters should be the preferred method of electronic speed control for the mitigation of water hammer.

SOFT START: THE IMPORTANCE OF ACCELERATION AND DECELERATION CONTROL IN COMBATING WATER HAMMER

With an understanding of the mechanics of water hammer, the system curve and the pump performance curve, we can explore the correct application of soft start technology to prevent water hammer.

Not all soft starters are created equal. Over the past 40 years the starting & stopping modes offered by soft starters have evolved considerably. Voltage, current, and more recently torque control, are all common approaches to starting and stopping. Each influences acceleration (and deceleration) but none provide direct control.

The most advanced soft start (and stop) mode is direct acceleration (and deceleration) control. This mode is ideal for pumping applications and the elimination of water hammer because it enables selection between a variety of starting and stopping profiles, depending upon the unique characteristics of the pumping system (pump and system curves).

For example, AuCom's XLR-8 technology provides selectable acceleration and deceleration profiles. These profiles are of particular benefit for pumping applications. Further, the ability to select and adjust a variety of control strategies makes it simple to tailor operation for optimal results no matter what the system characteristics.

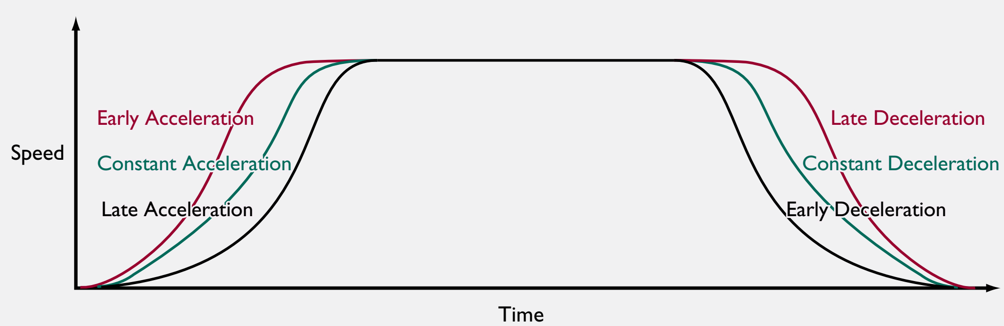

Figure 3: Acceleration and decleration control

APPLICATION OF XLR-8 PROFILES

Mode	Profile	Application
Starting	**Early acceleration**	Gets the pump up to pumping speed quickly ensuring water lubrication and reducing wear on thrust bearing (if applicable), then provides maximum control of flow for the rest of the start.
Stopping	**Early deceleration**	Ideal for open systems without non-return valves. For example, pumps lifting water from one level to another. Reduces pump speed promptly so that flow stops while still maintaining forward pump rotation as water drains from the pipes. This provides an effective stop and prevents any reverse pump rotation.
	Constant deceleration	Ideal for low head situations with high flow rates and long pipes. Provides a long and steady reduction in flow ensuring fluid momentum is gradually dissipated thus preventing any pressure surges.
	Late deceleration	Ideal for situations with flat system and/or pump curves. Provides an extended and gradual reduction in speed through the critical point of control then finishes the stop quickly once proper flow control has been achieved.

Summary

Water hammer (pressure surges) occurs from rapid changes in flow. Typically these rapid changes are associated with start/stopping of pumps and the opening and closing of valves.

Pressure traps can mitigate the damaging effects of these pressure surges.

Mechanisms for preventing the pressure surges in the first place include:

- controlling the opening and closing of valves to gradually change the flow.
- controlling the motor/pump speed during starting and stopping to gradually change the flow.

Preventing water hammer through control of pump speed:

- is easiest with steep system curves
- is best achieved by selection of pumps with a steep pump curve

If flow control can assist overall efficiency then use a VSD, in all other cases a soft start should be preferred.

Ensure the soft starter has acceleration/deceleration control and the ability to specify different acceleration and deceleration profiles.

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