Flow Science Incorporated
202 S. Lake Ave., Suite 294, Pasadena, CA 91101
(626) 304-1134 • FAX (626) 304-9427

Battery Powered Surge Mitigation (BPSM) – Description and Benefits

INTRODUCTION

This Technical Memorandum (TM), developed from Flow Science Incorporated's 38 years of experience in the analysis of hydraulic systems, provides a summary of:

- The causes of waterhammer and pressure surges in pumping and turbine systems,
- The current methods of surge control and their disadvantages, and
- A proposed novel Battery Power Surge Mitigation (BPSM) approach to surge control and the numerous unique advantages it has over current methods of surge protection for hydraulic systems.

CAUSES OF WATERHAMMER AND PRESSURE SURGES

Waterhammer and pressure surges in piping systems are created when a change in the pipeline flow rate occurs. The source of the change in flow rate is often due to the normal starting or stopping of a pump, or as a consequence of sudden loss of power to a pump, or load loss to a turbine that results in turbine runaway.

When a pumping system is shut down as part of normal operations, or by power failure, the hydraulic grade line (HGL) downstream of the pump station falls very rapidly. The rapidity of the pressure drop is controlled primarily by the rotating moment of inertia of the pump/motor system. If the inertia is high the HGL falls slowly, but for many pumping units it drops to the suction water elevation, or below, in a second or so. The rapid pressure drop (created by loss of power to the pump) travels out along the downstream pipeline as a pressure drop wave (*i.e.,* low pressure wave) moving at a speed of 500-4500 ft/sec, depending upon the pipe material, bedding, restraints and dimensions, and the fluid being pumped. For a condition where a pump is operating in an in-line booster configuration (receiving flow under pressure from a long upstream pipeline), sudden pump power loss will generate both a pressure drop wave at the pump discharge and a pressure upsurge wave on its suction side.

Since the steady flow HGL slopes down toward the pipeline discharge point, and in many cases the pipeline profile rises toward the discharge point, at some location along the profile the dropping HGL may fall below the invert of the pipe, thereby creating a vacuum in the pipe. If the HGL falls one atmospheric pressure head, (-34 ft approximately below the pipe crown), the absolute pressure in the pipeline will be equal to the vapor pressure of the fluid and it will begin to boil at ambient temperature. Once boiling occurs a vapor cavity will form at the crown of the pipe and the pressure downsurge wave will continue propagating along the pipeline leaving behind a pipeline under vacuum and filled with boiling water. When the downsurge wave reaches the discharge point, or other constant pressure point, it is reflected as a re-pressurization wave. This wave travels back up the pipe, removing the vacuum and stopping the boiling.

When there is an extensive vapor cavity it will tend to accumulate at some point in the pipeline (usually at a break in the slope or local high point) and collapse explosively. The net result is a localized region in the pipe that is subjected to an extremely high impulsive pressure, known as a waterhammer. As the re-pressurization wave finally returns to the pump station it may close the pump check valve suddenly and create an additional waterhammer. For the condition of an inline booster, the pressure upsurge on the suction side of the pump will travel along the suction piping, raising its pressure. When the upsurge wave reaches the supply source, it will reflect and return to the pump and generate a pressure drop wave with similar potential consequences as described for the discharge pipeline.

Similar problems can occur in hydro-electric generating stations and penstocks. When a turbine generating set loses load the out-of-balance torque causes the turbine and generator set to accelerate. For units driven by Francis-type turbines, the higher speed chokes the flow and a pressure upsurge wave is generated in the supply piping, while for axial flow units the acceleration results in a drop in upstream pressure as the flow through the unit increases. Control of surges is generally accomplished by added rotating inertia that will slow the rate of acceleration so that flow control valves may be activated. Surge towers may also be installed to limit the propagation of the pressure waves.

For all types of hydraulic piping systems there are three areas of possible damage that may result from pressure surges: i) the maximum surge pressure may exceed the allowable surge pressure for the pipeline (leading to its possible rupture), ii) the minimum surge pressure may cause collapse of the pipeline due to the combination of negative pipeline pressure combined with soil loads, and/or iii) vapor cavity formation and collapse may occur, leading to a high localized pressure pulse that can rupture the pipeline, or damage its corrosion protection coating leading to later failure as a result of accelerated long-term corrosion.

CURRENT METHODS OF CONTROL OF WATERHAMMER AND PRESSURE SURGES

Control of waterhammer arising from pump operations can currently be accomplished by one of five basic methods, some of which involve storing energy to maintain the flow after a power loss.

1. Increase the rotating inertia of the pump/motor system. This may be accomplished by adding a flywheel to the pump/motor system. The disadvantages of flywheels include: a) they are seldom practicable on long pipelines because of the size of flywheel required, b) the use of flywheels when variable frequency drives (VFD's) are employed requires special

design attention to avoid torsional resonance problems, c) flywheels are generally not possible for fully submerged pump/motor units, and d) flywheels are generally not possible as a retrofit option for existing pumps.

2. Install vacuum relief valves on the pipeline. Vacuum relief valves can be added to help control minimum surge pressures along a pipeline. The disadvantages of vacuum relief valves include: a) vacuum valves do not control high pressures generated by a surge event, b) numerous vacuum relief valves may be required, as frequently as every 500 ft along the pipeline, c) vacuum valves allow air to enter the pipeline whenever the internal pressure falls below atmospheric pressure and the air admitted to the pipeline must be released in a controlled manner to avoid valve slam when the pipeline is repressurized, d) vaults for the valves may be required if the valve needs to be buried due to roadway considerations, e) in potable water systems, there is the potential for contamination to enter the pipeline when the vacuum relief valve is opened, f) in sewage systems there is the potential for odor release, and g) a regular maintenance program is required for vacuum relief valves and cleaning may be a particular challenge with sewage systems, which accumulate grease.

3. Install pressure relief/surge anticipator valves on the system. These valves open to allow high pressures created in the system to bleed off, usually to the atmosphere or to the suction pipeline at a pump station, when a high-pressure set point on the valve is exceeded, or in an 'anticipator mode' opening when the pressure in the pipeline drops below a low-pressure set point on the valve, following loss of power to a pump. The disadvantages of relief valves include: a) relief valves do nothing to alleviate low-pressure problems, b) the opening of a relief valve can create more severe low-pressure problems, including possible vapor cavity formation, if they open too quickly, and c) the discharge flow from the relief valve, if the discharge is to atmosphere, must be handled via a drain or storage area.

4. Install a pressurized (*i.e.,* closed) surge tank that has energy stored in its compressed air that will continue flow after the pump has stopped and until such time as the flow in the pipeline reverses. Disadvantages of pressurized surge tanks include: a) pressurized surge tanks are usually impracticable on low head systems or long, flat pipelines, b) an air compressor and level control equipment may be needed for an 'air-over-water' type (note the potential for objectionable noise with an air compressor near residential areas), or the periodic filling of air and the replacement of the tank bladder is required for a 'bladder' type, c) site constraints at existing facilities may prevent the installation of large volume surge tanks, d) in raw sewage systems, pressurized surge tanks must be maintained frequently to ensure that they are always in good working order, e) for a booster pump arrangement surge tanks may be required on both the suction and discharge side of the pump, and f) pressure vessel codes require periodic removal from service and inspection.

5. Install an open surge tank (*i.e.,* surge tower or standpipe). Open surge tanks may be used for low head systems if the standpipe height is not impractical. As with pressurized surge

tanks, open surge tanks will continue flow after the pump has stopped and until such time as the flow in the pipeline reverses. The disadvantages of open surge towers include: a) the height of a surge tower may be impracticable or objectionable, b) the seismic structural stability requirements of the surge tower may limit its height and therefore its application, and c) open surge tanks may be objectionable for sewage systems due to the potential for odors and cleaning requirements.

PROPOSED BATTERY POWER SURGE MITIGATION (BPSM)

Flow Science is proposing a new and vastly superior approach to the control of waterhammer and pressure surges arising from pump operations: the use of a Battery Power Surge Mitigation (BPSM) system that comprises a battery coupled with pump controls designed to respond as follows: When the pump motor experiences a sudden loss of power, or when a pump is turned off for normal operation, the BPSM system senses the loss of power to the pump and the BPSM activates to provide power and control as needed to initiate a slow, controlled ramp down of the pump and avoid generating hydraulic surges, waterhammer, and vapor cavity formation.

In effect the battery "floats" on the system and immediately acts to provide the energy necessary to keep the pump(s) operating in the event of a power supply line failure and complete an initiated slow ramp down of the pump(s). The ramp down rate of the pump is then designed to achieve a sufficiently gradual rate of change in pumped flow that will completely avoid generating any waterhammer and problematic pressure surges within the system. The ramp down rate can be achieved via either a) the use of separate VFDs for each pump, b) the use of inverters to slowly reduce the voltage/amplitude to the pump motor(s) to slowly reduce the pump speed, or c) maintaining a constant pump speed while initiating the slow closure of a pump discharge control valve. The ramp down rate may be linear or non-linear as required to optimize battery sizing and the surge response of the system. A power switch may be needed to isolate and later re-engage the batteries from/to the main power supply. The batteries are re-charged when the primary power supply to the site is restored. The batteries may further be sized and controlled to provide 'load-shaving' to reduce peak power consumption at the station while continuously reserving/maintaining a sufficient portion of the battery charge to be ready to power a controlled pump ramp down should primary power loss occur.

During normal pump start, the same methods are used in reverse to initiate a slow pump ramp rate to increase flow gradually in the system to avoid startup surges. The two basic design parameters for the BPSM are the power necessary to keep pumps operating and the amount of stored energy required, which is set by the pump speed ramping rate necessary to avoid any surges. Flow Science's surge analysis software, proven in 38 years of analyzing thousands of hydraulic systems, easily provides the appropriate pump speed ramping rate.

Advantages of the proposed BPSM system include:

- The BPSM system avoids all of the disadvantages outlined above for current surge control equipment including space, maintenance requirements, odors, and air entrainment for vacuum valves.

- The BPSM system avoids the need to handle discharge flows for pressure relief valves.

- The BPSM system avoids the site footprint and installation challenges of surge tanks or surge towers.

- The BPSM system can be used for submersible pumping applications.

- The BPSM system can be retrofitted to existing pumping systems.

- The BPSM system can reduce the high startup electrical current draw of constant speed pumping units, which can reduce peak power loads.

- The BPSM system can be used to add speed control to pump stations that formerly were designed with only constant speed pumps operated as on/off (fill-and-draw) systems controlled by wet well water surface elevations. Conversion to variable speed pumping may enable more efficient (reduced peak) power consumption for the system compared to intermittent full speed pumping.

- The BPSM system can eliminate vapor cavity formation in pipelines and thereby completely obviate the need for vacuum relief valves for surge protection (note that vacuum valves may still be necessary for pipeline drainage).

- The BPSM system's on-site battery may provide a "cleaner" power supply to the pumps in scenarios where small "dips" in the power supply could trigger pump shutdowns.

- The storage capacity of the BPSM system may be further used to provide 'load-shaving' to reduce peak power consumption at the station while continuously reserving/maintaining a sufficient portion of the battery charge to be ready to power a controlled pump ramp down should primary power loss occur.

- The BPSM may be used to control/brake the rate at which a hydraulic turbine goes to runaway following sudden electrical load loss and avoid waterhammer and surges associated with hydraulic turbines.

The advent of lithium ion batteries and other battery chemistries, and the control systems developed for electric automobiles and stationary battery power management systems, make BPSM systems viable for even very large pump stations, For example, Con Edison and a partner, 174 Power Global, recently announced a 100-MW/400-MWh battery at the site of a former fossil fuel plant near the East River in Astoria, Queens. The company also has a 2-MW storage system in Ozone Park, Queens.

King County (WA) is currently working with Jacobs Engineering and Flow Science in the design of a BPSM to solve potential wastewater overflow problems that could result from power loss at the West Point Wastewater Treatment Plant.

ANALYSIS OF WATERHAMMER AND PRESSURE SURGES

The pressures created by changing flow conditions in piping systems can be determined quite accurately by the application of Newton's Laws of Motion. Flow Science has developed a set of computer programs that solve the waterhammer wave equations (Newton's Laws) for situations involving pump power failure, start up and shutdown, valve operations, and turbine load loss. These computer codes, which use the method-of-characteristics solution technique for the appropriate equations, allow computation of the pressure and flow at any point in a distribution network at prescribed times after pump startup, shutdown, power failure, valve operation, or turbine loss of load. The codes have been developed over a period of more than 38 years and have been extensively tested and validated in the field. Flow Science is able to perform a surge analysis of any system to determine optimum response rates and sizing for a BPSM system that will provide complete surge protection.

CONCLUSION

Waterhammer and pressure surges comprise a substantial risk to water supply and wastewater collection systems. The use of a BPSM system to allow controlled shutdown and startup can avoid these risks in a way that offers unique advantages over any other current method of surge control.

To discuss how Flow Science can assist with the development of a BPSM system for your application contact Vice President Mark Sauter, P.E. at msauter@flowscience.com or telephone (626) 304-1134.

By
Li Ding, Ph.D., P.E., President
E. John List, Ph.D., P.E., Principal Consultant
Mark Sauter, P.E., Vice President
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