Waterhammer Modeling in Thermo-Hydraulic Systems

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There are two types of waterhammer transients observed in thermo-hydraulic systems during the transient due to a liquid's inertia moving against the gas and then abruptly coming to a stop: gas compression and gas condensation. Depending on the amount of gas present (which dictates if the system is stagnated due to a waterhammer or an inertial slowdown), the transient could be damaging to the system either structurally due to failed supports or piping, or by a relief valve being lifted (if present in the system). The compression and consequential rarefaction waves (waves that induce flow in the opposite direction of nominal flow, which results in the check valve closing) that travel through the system could also induce secondary waterhammers due to a check valve slam.

The conditions that will lead to waterhammer transients are numerous. A few examples of potential waterhammer transients include: gas (condensable or non-condensable) resident in piping when a pump is started, a rapid closure of a valve, or column separation and rejoining following a stop and restart of a system.

Condensation induced waterhammer transients result in much more energetic transients compared to non-condensable gas-water waterhammers. Steam-water waterhammer transients can also behave as non-condensable gas-water waterhammer transients if the water interfacing the gas is equal to the temperature of the gas, which therefore reduces or even eliminates the condensation of the gas.

Condensation induced waterhammer transients are also more energetic due to the very rapid pressure rise,which is in the range of a few milliseconds, whereas non-condensable gas waterhammers might have rise times in the range of 10 milliseconds or higher.

Typically, the goal is to maintain systems at a "liquid solid" state, where the entire piping system is completely filled with liquid and no gas is present. However, gas could leak into the system due to various pathways or methods and it might be difficult to immediately detect. Thus, it is more reasonable to engineer a system for a "liquid full" state: one in which some gas could exist in the piping, and the pumps, valves and piping can continue to fulfill the system design function.

Even though waterhammer phenomena are complex in nature due to the large number of components in the system and the complexity of the piping system, there are tools available that allow for a complete evaluation of the system. Once the system's model is developed in one of the available computational tools, the system could be evaluated with a matrix of transients where, for example, the gas volume is varied. Then, the pressures and forces from each transient are compared against the allowable peak pressures and forces in the system, providing an operability range for a system where the presence of gas will not necessarily lead to qualifying the system as inoperable. This methodology enables cost effective operation of a system allowing for removal of over-conservatism in the safe operation of piping, pumps, valves, etc.

Figures 1 and 2 demonstrate the process of identifying the acceptance criteria for a system, where the peak pressure and force from numerous transients were compared against the allowable pressure and force for the system, respectively. Each data point represents a transient that was analyzed with one of the computational tools. As seen from the keys, the different color and shape points represent sampling at different times, thus each point of the same type (color/shape) represent a run at increasing gas void volumes.

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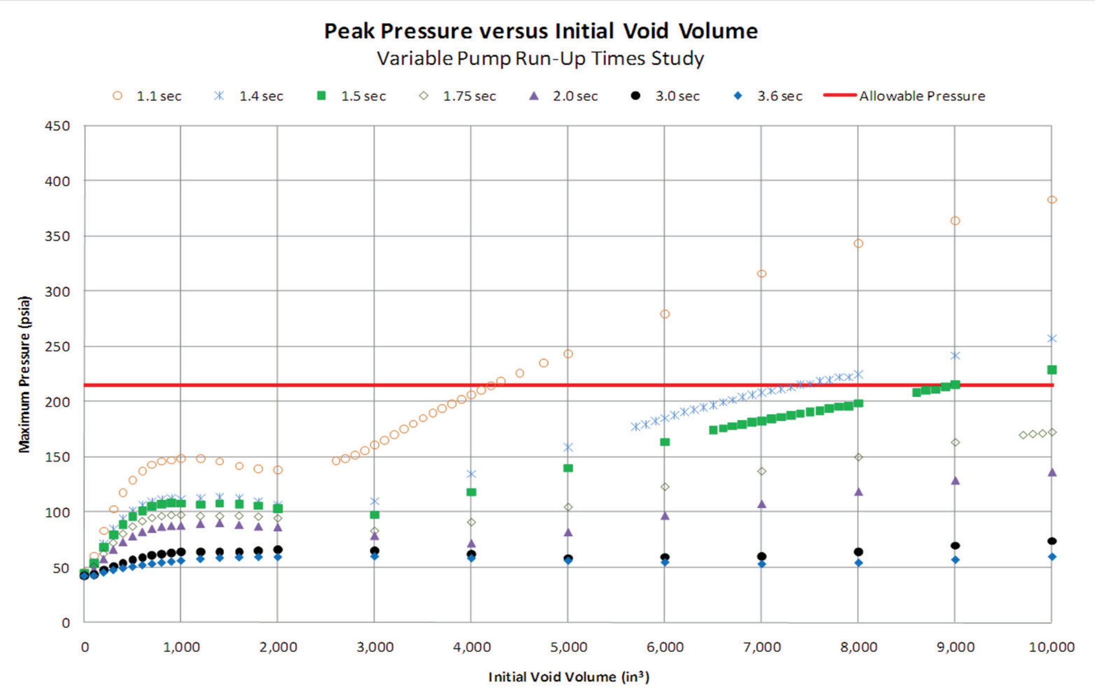

Figure 1: Pressure Versus Initial Void Volume

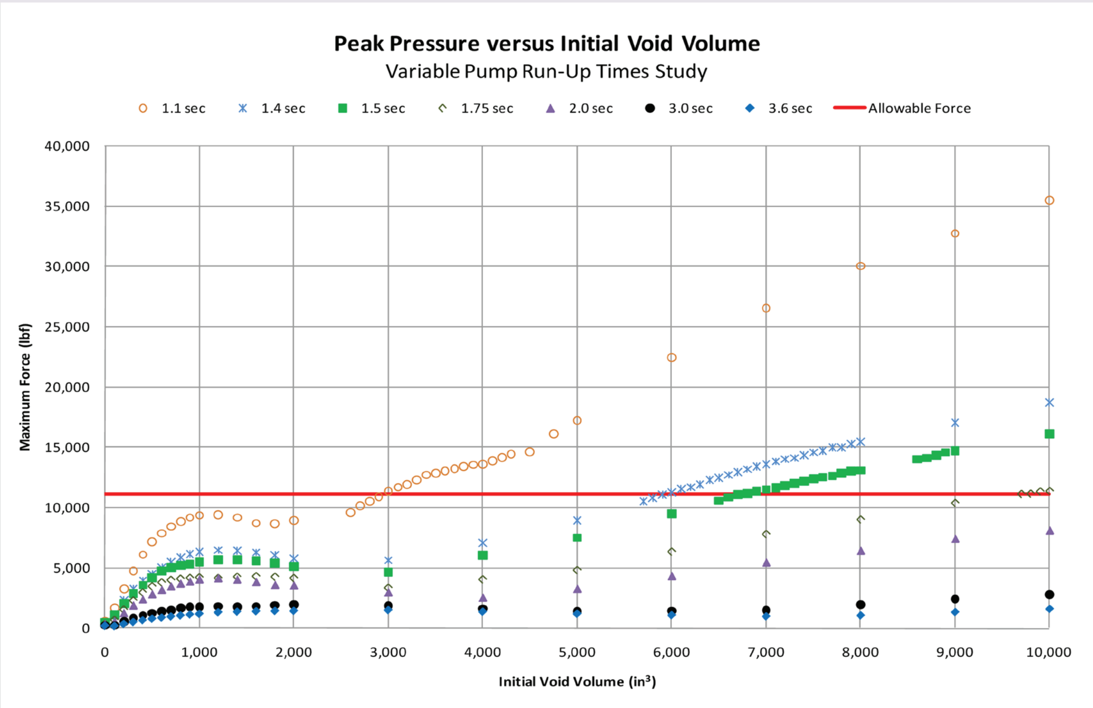

Figure 2: Force Versus Initial Void Volume

Fauske and Associates, LLC has performed numerous such evaluations. Multiple computational tools have been utilized and many additional ones developed to optimize the computation. Such optimization allows for a large number of scenarios to be evaluated leading to an optimal solution. As a result, the client is provided with an answer where unnecessary conservatism has been removed and the system can be operated cost effectively, while maintaining safe/acceptable operating conditions.