Non-Condensable Gas-Water Waterhammer Analysis

By: Basar Ozar,Ph.D., Principal Nuclear Engineer & Damian D. Stefanczyk, P.E., Director, Thermal Hydraulics Services

In 2008 the Nuclear Regulatory Commission (NRC) issued Generic Letter 2008-01 (NRC, 2008) which requires the U.S. (United States) electric utilities to address issues related to possible intrusion of noncondensable gases into the suction and discharge piping of the Emergency Core Cooling Systems (ECCS) for both Boiling Water Reactors (BWRs) and Pressurized Water Reactors (PWRs). This document focuses on the issues related to the intrusion of gases on the discharge piping of ECCS.

For the discharge piping, the gases that could enter the piping include: (a) air as a result of outage work and maintenance activities or leakage into water filled volumes at sub-atmospheric pressure (where applicable), (b) nitrogen that could evolve (exit solution) in some PWR designs if gas saturated water leaks through the accumulator isolation check valve into the lower pressure ECCS injection systems and (c) radiolytic gases (oxygen and hydrogen) that could exit solution if the Reactor Coolant System (RCS) water leaks through the RCS isolation check valves into the injection piping. The extent of the radiolytic gases in solution is dependent on the specific water chemistry that is used for each reactor. The details of any system design and maintenance have a first order influence on the potential for, and the consequences of, gas evolution and accumulation in the pump discharge piping.

Gas-water waterhammer events can occur resulting from a flow transient (such as a pump start) with a gas volume resident in the system piping (on the discharge side of pumps). These fluid transients could be generated, for example, from a pump surveillance test or pump start or valve opening due to an accident sequence with the important response features being the peak pressure and force imbalances developed on the piping.

Several NRC/NEI (Nuclear Energy Institute) public meetings were held to explain the intent of the generic letter and the manner in which individual plant assessments could be performed and documented. In these meetings, the NRC emphasized that the major concerns for gas intrusion are the possible challenges to the performance since this could jeopardize the operability of the safety injection systems. Moreover, the NRC staff has noted that gas-water waterhammer events have been experienced in plant operations with some damage to components (hangars, snubbers, etc.). However, none of these resulted in challenges to the operation of the safety injection systems. Consequently, the potential for gas-water waterhammer events to occur needs to be evaluated and acceptance criteria need to be formulated for the maximum accumulated noncondensable gas volume(s) that would not prevent/inhibit the system from performing its intended function.

Waterhammer tests were performed and an experimental database was developed for the Pressurized Water Reactor Owners Group (PWROG) and are reported in FAI/08-70 (2008a). These tests included a long pipe length (greater than 100 feet), a long highpoint configuration, multiple pipe bends, a pump start transient, propagation to, and reflection from, a water storage tank, etc., and illustrate that the transient response is oscillatory in nature. As demonstrated by the experiments in FAI/08-70, the pressure transient generated in a highpoint acoustically propagates throughout the water-filled piping (upstream and downstream) from that location. The resulting propagation of the initial compression wave and the consequential reflected rarefaction and compression waves are imposed on pipes of different lengths and diameters. Furthermore, the pressures and forces reach a maximum value and then decay, usually after the first peak and, if not then ,after the second peak for all cases.

The computer code GW2 (FAI/08-172, 2008b) was developed as part of this PWROG program to perform non-condensable gas-water waterhammer analyses. The code is capable of evaluating pressures, flows, and unbalanced forces in various components in the piping system based on different gas accumulation assumptions. The code is validated with standard waterhammer problems (Chaiko and Brickman, 2002; Streeter, 1978) and experiments (FAI/08-70, 2008a). Examples of the pressure time history and the force time history comparison with experimental data are provided in Figure 1 and Fire 2, respectively.

Acceptance criteria for the maximum accumulated noncondensable gas volume(s) that would not prevent/inhibit the system from performing its intended function can be developed using the GW2 code. Acceptance criteria are evaluated for three parameters: pressure, force, and velocity necessary to slam any of the check valves in the system. A check valve slam might not damage the system, but such an event is undesirable nonetheless, and therefore was used when considering the acceptance criteria. Typically, a system will be challenged by a force imbalance (not by over-pressurization) with a piping support undergoing damage or one of the check valves slamming. However, for systems that contain pressure relief valves, the pressure increase might be the limiting factor. Therefore, for a system like RHR, where pressure relief valves are present, the acceptance criteria are evaluated by finding the limiting force that could damage the system (Figure 3), the minimum pressure that will lift the relief valve(s) (Figure 4) or the void volume necessary to lead to conditions favorable for a check valve slam (Figure 5). As shown in the plots, the code can be utilized to run a large array of transients to optimize the solution. The run time of the code is much shorter than other codes intended for such analyses, e.g. RELAP5, GOTHIC, since it was developed specifically and solely for these types of transients. Furthermore, the code is much more stable numerically than the other aforementioned codes, which also greatly reduces the time required to execute the large array of transients. However, due to the wide spread familiarity and applicability of the other codes in the industry for use with waterhammer transients, GW2 was benchmarked against RELAP5 to demonstrate its capability to model such transients. Both codes produced equivalent results.

References

Chaiko and Brickman. (2002). "Models for Analysis of Water Hammer in Piping with Entrapped Air". March, 2002: Transaction of ASME, p. 194, Vol. 124.
FAI. (2008a). "Gas-Voids Pressure Pulsations Program". FAI/08-70: Fauske & Associates, LLC.

FAI. (2008b). "GW2 Code Description". FAI/08-172: Fauske & Associates, LLC.

NRC. (2008). Managing Gas Accumulation in Emergency Core Cooling, Decay Heat Removal, and Containment Spray Systems. Generic Letter 2008-01: Nuclear Regulatory Commission.

Wylie/Streeter. (1978). "Fluid Transients". New York: McGraw-Hill.

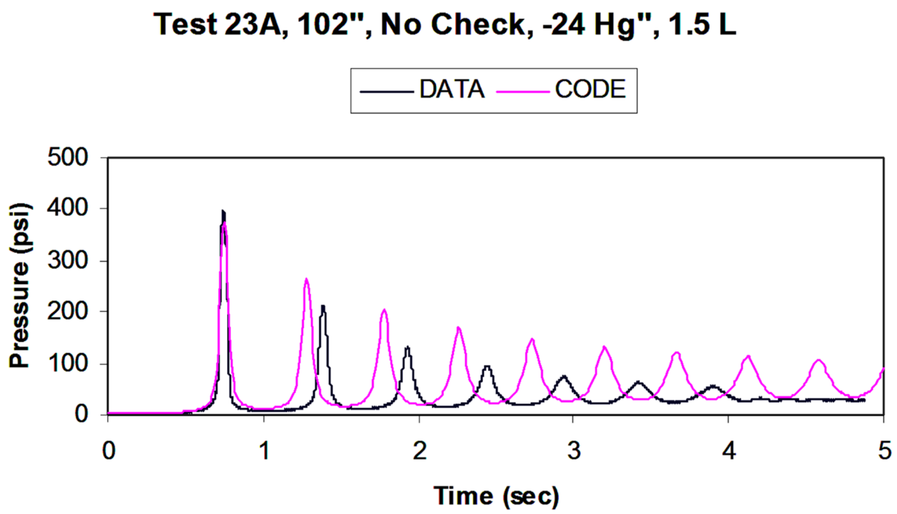

Figure 1 Comparison of pressure calculated by GW2 against experimental data collected at FAI for the PWROG

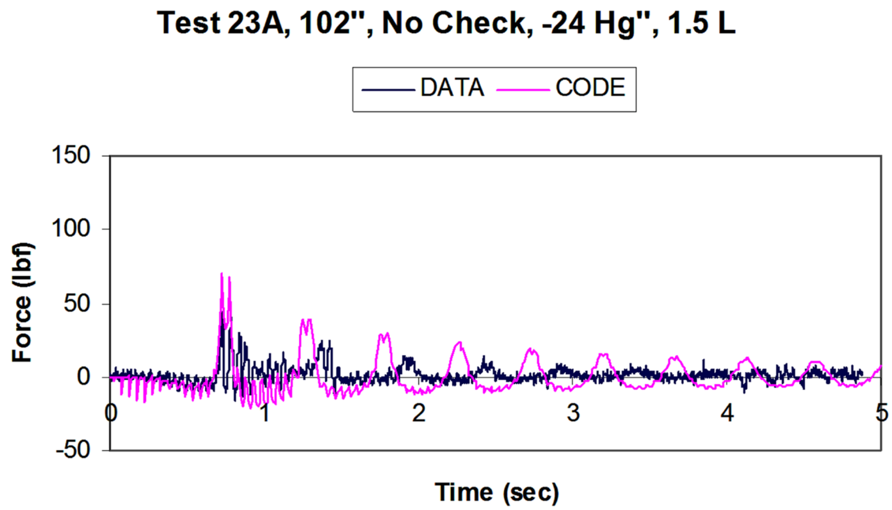

Figure 2 Comparison of force calculated by GW2 against experimental data collected at FAI for the PWROG

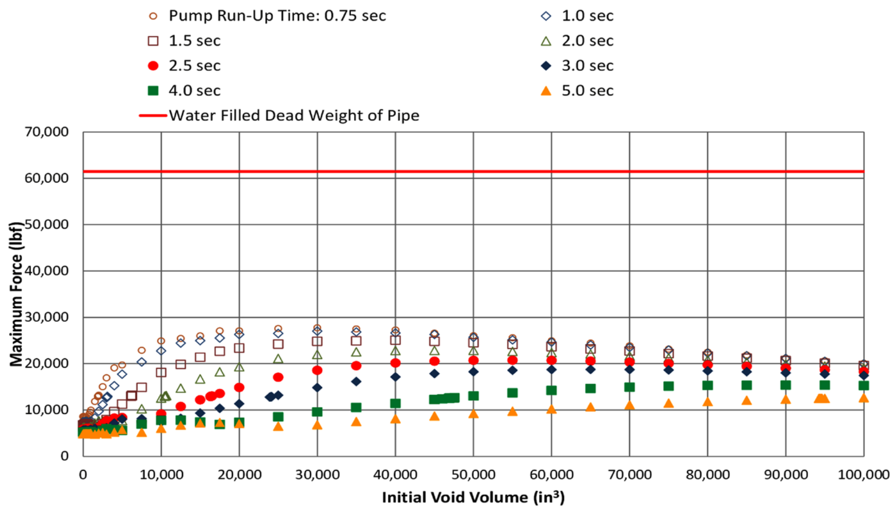

Figure 3 Force versus void volumes for a sample system with pump run- transient

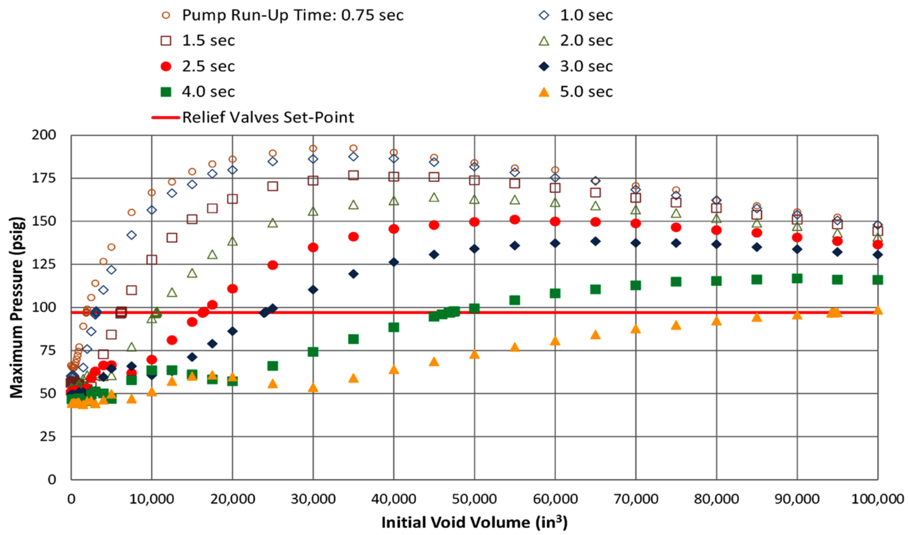

Figure 4 Pressure versus void volumes for a sample system with pump run - transient

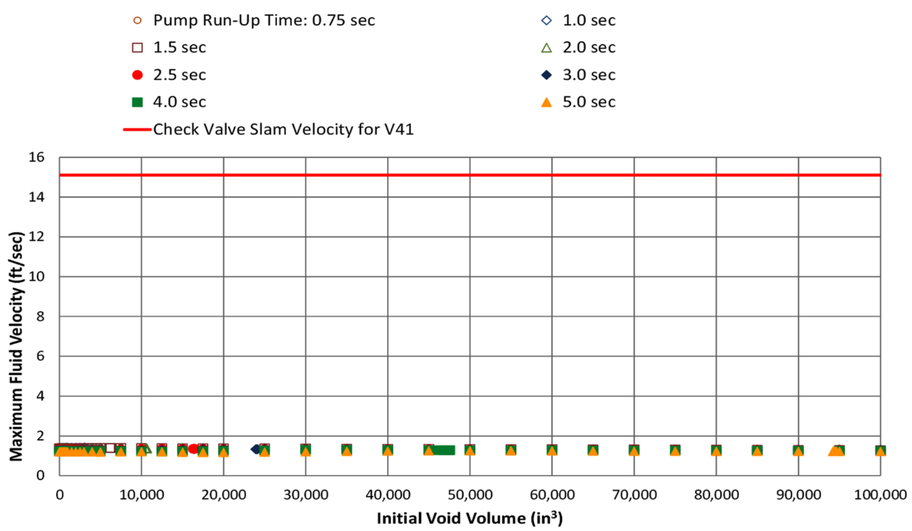

Figure 5 Check valve slam analysis results for a sample with pump run - transient

For more information, contact:

Basar Ozar, Ph.D.
Principal Nuclear Engineer
(630) 887-5276
ozar@fauske.com

Damian Stefanczyk, P.E.
Director, Thermal Hydraulics Services
(630) 887-5208
stefanczyk@fauske.com

Fauske & Associates, LLC
16W070 83rd Street
Burr Ridge, IL 60527

FAUSKE & ASSOCIATES, LLC

www.Fauske.com