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Calculation of Forces on Reactor Containment Fan Cooler Piping

Joseph S. Miller/EDA, Inc.
6397 True Lane
Springfield, VA 22150
Phone: 703 597-2459, Fax: 703 313-9138
e-mail: JoeMiller@edasolutions.com

Kevin Ramsden/Exelon Nuclear
Mechanical Engineering, LLC
4300 Winfield Road
Warrenville, IL 60555
Phone: 630 657-3892 , Fax: 630 657-4328
e-mail: Kevin.ramsden@exeloncorp.com

ABSTRACT

The purpose of this paper is to present the results of the Reactor Containment Fan Cooler (RCFC) system piping load calculations. These calculations are based on piping loads calculated using the EPRI methodology (Refs. 1 & 2) and RELAP5 (Ref. 3) to simulate the hydraulic behavior of the system. The RELAP5 generated loads were compared to loads calculated using the EPRI GL 96-06 methodology. This evaluation was based on a pressurized water reactor's RCFC coils thermal hydraulic behavior during a Loss of Offsite Power (LOOP) and a loss of coolant accident (LOCA). The RCFC consist of two banks of service water and chill water coils. There are 5 SX and 5 chill water coils per bank. Therefore, there are 4 RCFC units in the containment with 2 banks of coils per RCFC. Two Service water pumps provide coolant for the 4 RCFC units (8 banks total, 2 banks per RCFC unit and 2 RCFC units per pump).

Following a LOOP/LOCA condition, the RCFC fans would coast down and upon being reenergized, would shift to low-speed operation. The fan coast down is anticipated to occur very rapidly due to the closure of the exhaust damper as a result of LOCA pressurization effects. The service water flow would also coast down and be restarted in approximately 43 seconds after the initiation of the event. The service water would drain from the RCFC coils during the pump shutdown and once the pumps restart, water is quickly forced into the RCFC coils causing hydraulic loading on the piping. Because of this scenario and the potential for over stressing the piping, an evaluation was performed by the utility using RELAP5 to assess the piping loads. Subsequent to the hydraulic loads being analyzed using RELAP5, EPRI through GL 96-06 provided another methodology to assess loads on the RCFC piping system. This paper presents the results of using the EPRI methodology and RELAP5 to perform thermal hydraulic load calculations and compares them.

NOMENCLATURE

EPRI – Electric Power Research Institute
CIWH - Condensation Induced Waterhammer
LOCA - Loss of Coolant Accident
MSLB – main Steam Line Break
RCFCs – Reactor Containment Fan Coolers
SX - Emergency Service Water System

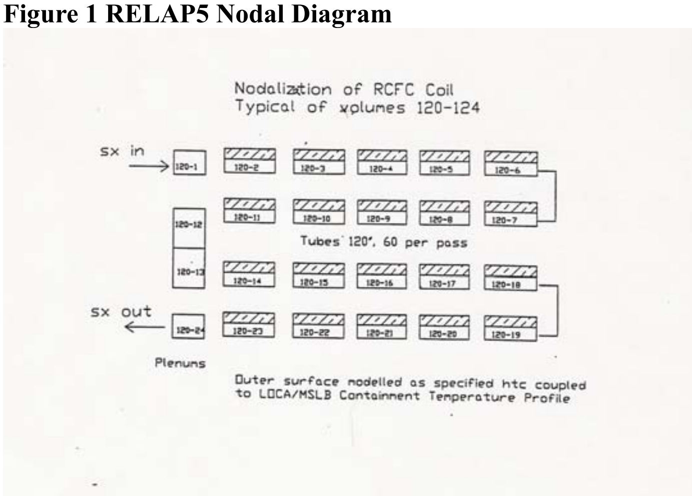
INTRODUCTION

Following either a Loss of Coolant Accident (LOCA) or a Main Steam Line Break (MSLB) concurrent with a Loss of Offsite Power (LOOP), pumps that supply cooling water to reactor containment fan coolers (RCFCs) and fans that supply air to RCFCs will temporarily lose power. Cooling water flow will stop due to the loss of pump head. Boiling may occur in RCFC tubes, causing steam bubbles to form in RCFCs and pass into the attached piping, creating steam voids. As service water pumps restart, accumulated steam in the fan cooler tubes and piping will condense and the pumped water can produce a waterhammer when the void closes. Hydrodynamic loads introduced by such a waterhammer event could potentially challenge the integrity and function of RCFCs and associated cooling water system components. The U.S. Nuclear Regulatory Commission (NRC) Generic Letter 96-06 identified potential issues for waterhammer effects during postulated events that can cause potential damage to service water systems. In response to GL 96-06, the Electric Power Research Institute (EPRI) and the nuclear power plant owners developed methodologies to evaluate these events. The EPRI methodologies are presented in References 1 and 2.

Another methodology used by the utility was to calculate the hydraulic loads using RELAP5 (Ref. 3). RELAP5/MOD3 is a "best estimate" system code suitable for the analysis of all transients and postulated accidents in Light Water Reactor (LWR) systems, as well as the full range of operational transients. RELAP5 can also be used to model piping systems that contain two-phase and sub cooled liquid. The one dimensional RELAP5/MOD3 code is based on a non-homogeneous and non-equilibrium model for the two-phase system that is solved by a fast, partially implicit numerical scheme to permit economical calculation of system transients.

The RCFC system was modeled using RELAP5 and hydraulic forcing functions were developed from these analyses. The RELAP5 model was initialized using option 4 to include a small amount of air in the fluid. The fraction was kept as small as possible, typically less than 25% of what could be dissolved in the fluid. The main reason for the air was not to get cushioning effects, but rather to prevent negative pressures from terminating the computer run during spiking behavior. Draindown of the RCFC system was determined dynamically by modeling the boundary conditions of pump coast down simultaneous with LOCA temperatures and heat transfer effects on the fan coolers using RELAP5. The boundary conditions and modeling assumptions were selected to maximize the void creation and maximize the potential for dynamic effects on SX pump restart. A postprocessor was developed and used to calculate the forces from RELAP5 generated pressure, densities, fluid velocity and user provided areas. The RELAP5 nodal diagram for the RCFC is shown in Figure 1.

Figure 1 RELAP5 Nodal Diagram



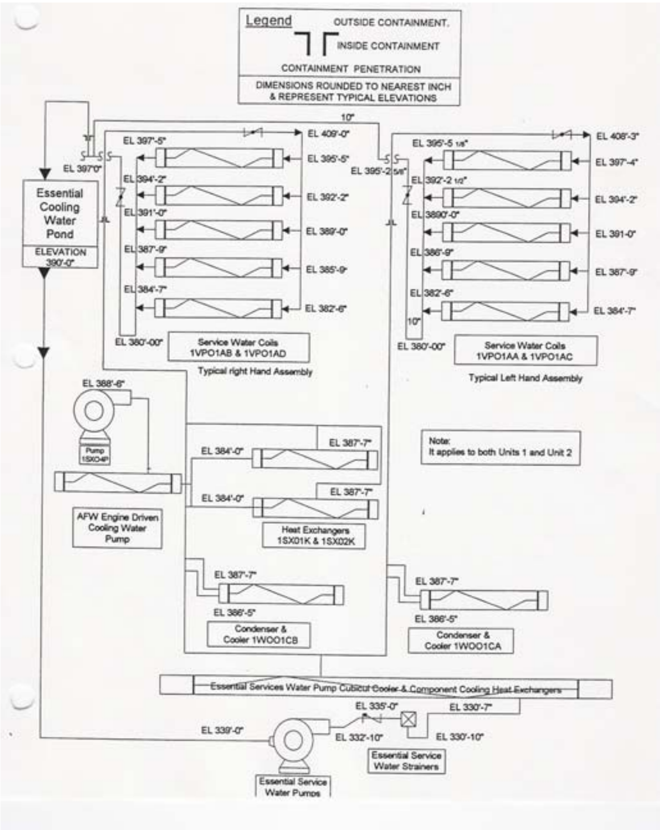
DISCUSSION

The purpose of this paper is to provide a comparison of thermal hydraulic load calculations based on using EPRI methodology (Ref. 1 & 2) and using RELAP5 simulator to determine the hydraulic loads of the RCFC system subsequent to a LOOP and a LOCA. This paper discusses the results of the evaluation of Reactor Containment Fan Cooler (RCFC) coils thermal hydraulic behavior during a LOOP/LOCA using the EPRI GL 96-06 methodology and RELAP5.

A diagram of the RCFC system is shown in Figure 2. The RCFC consist of two banks of service water and chill water coils. There are 5 SX and 5 chill water coils per bank. Therefore, there are 4 RCFC units in the containment with 2 banks of coils per RCFC. Two Service water pumps provide coolant for the 4 RCFC units (8 banks total, 2 banks per RCFC unit and 2 RCFC units per pump). In normal operation, both sets of coils have a flow, and the RCFC fan is operating in a high speed mode. Following a LOOP/LOCA condition, the fans would coast down and upon being reenergized, would shift to low-speed operation. The fan coast down is anticipated to occur very rapidly due to the closure of the exhaust damper as a result of LOCA pressurization effects. The exhaust dampers would also have the effect of trapping air, creating a low flow, or an upswept zone around the coils that would not favor condensation. The SX flow would also coast down and be restarted in approximately 43 seconds after the initiation of the event. The chill water would not be restarted in a typical design basis accident scenario.

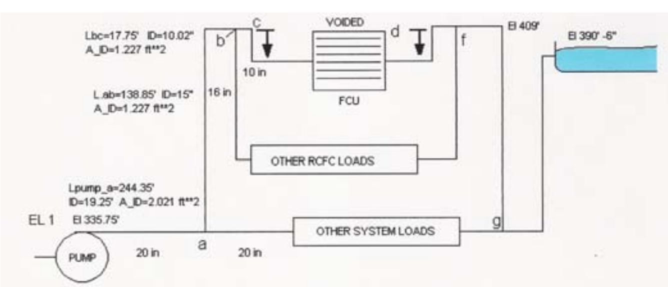
The schematic of the RCFC/SX system is shown in Figure 3. The designation on Figure 3 refers to the same designation presented in Ref. 1 for an open loop system (See Figure 7–1 of Ref. 1). The designation of c represents the front edge of the void and d represents the back edge of the void. The void is contained in the volume of the fan cooler unit (fcu) and the attached piping including the 10” riser. The fcu is represented in this case as 5 coils (1/2 of 1 RCFC unit). The flow path is as follows: Water leaves SX pump and branches from a 36” header pipe into a 20”, which is designated as the pump location. From the 36 x 20 tee, the flow travels 244.35’ to a 20” x 16”, which is designated as point a. From point a, the flow travels through a 16” pipe for 138.85’ to the first flow split into a 10” riser going to the 5 fcu coils. At this point, which is designated as point b, the flow is split by ¼ to ¾, with ¼ of the flow going down the 10” riser and feeding the 5 coils and the remaining ¾ flow steam proceeding to the other half of the RCFC 2D and to RCFC 2B. The point designated as c is located in the 10 “ riser at 17.75’ below the 16” x 10” split designated as point b. The 10” riser evenly distributes the flow through the 5 coils through 4” pipes that tee from the 10” riser. These 4” pipes run in parallel and are reduced to 3” pipes, which go into a coil. The point designated as c is the front edge of the void.

Figure 2 RCFC SYSTEM



The steps that are specified by the EPRI methodology are: 1) Evaluate the System, 2) Model System Hydraulics, 3) Determine Condensation Induced Waterhammer (CIWH) magnitude, 4) Determine Potential Closure Locations, and 5) Determine Column Closure Waterhammer (CCWH) Magnitude and Pulse Characteristics.

Figure 3 Schematic of RCFC According to EPRI Methodology



The most significant aspect of the calculation using the EPRI methodology was determining the peak pressure pulse. The peak pressure pulse is affected by pressure reflections from other obstruction downstream from the initial pressure pulse. During a column closure event, the pressure rises as the void closes. This rising pressure travels upstream and downstream from the closure location. As the pressure pulse encounters area changes, a portion of the original pressure wave is reflected back toward the closure location. The reflected pressure wave will add to the pressure it encounters in a positive or negative manner. If the reflection comes from an expansion, then it will have a negative magnitude and cause the oncoming pressure to be reduced. The peak pressure will be "clipped" if the reflection reaches the closure location before the pressure peaks. In the case of the RCFC pressure pulse evaluated in this paper, the distance from the pressure pulse to the expansion at point "b" is only 17.75', therefore pressure clipping is expected. Ref. 1 has provided guidance for determining pressure clipping. Since References 1 and 2 are proprietary documents, only the final results will be presented here.

The peak pressure is checked for "clipping" using Table 5-3 of Reference 1. Point "a" is checked (See Figure 3). The primary factors used to calculate the peak pressure are: length of void (L_{cd}), release of non-condensables to calculate the cushioned velocity, determine the pressure pulse shape, determine the pressure pulse magnitude, rise time and peak pressure duration, and determine reflective pressure wave. From these elements, the clipped peak pressure can be determined. The pressure reflection from the first major expansion in the piping system will cause the initial pressure wave created from the water hammer to be clipped (i.e., reduced) based on the speed of the refection wave to and from the major expansion and the degree of expansion. In addition, the pressure pulse is cushioned by the non-condensables in the water.

The unclipped pressure is 126 psi and the clipped pressure pulse is 64 psi. The system pressure is added to this value. The resultant pressure pulses using the EPRI mythology with cushioning and non-cushion effects considered are presented in Figure 4.

RELAP5 was used to simulate the LOOP/LOCA event. The pressure pulse calculated from the RELAP5 simulation is shown in Figure 5. As you can see from Figure 5, the pressure pulse from the RELAP5 calculation is slightly larger than the pressure pulses calculated using the EPRI methodology.

To evaluate the loads on the piping system, it was assumed that PA represented the force on the piping system. Figure 6 shows that hydraulic load of the RELAP5 pulse is greater than the hydraulic load of the EPRI pulses.

Figure 4 Pressure Pulse Using EPRI Methodology

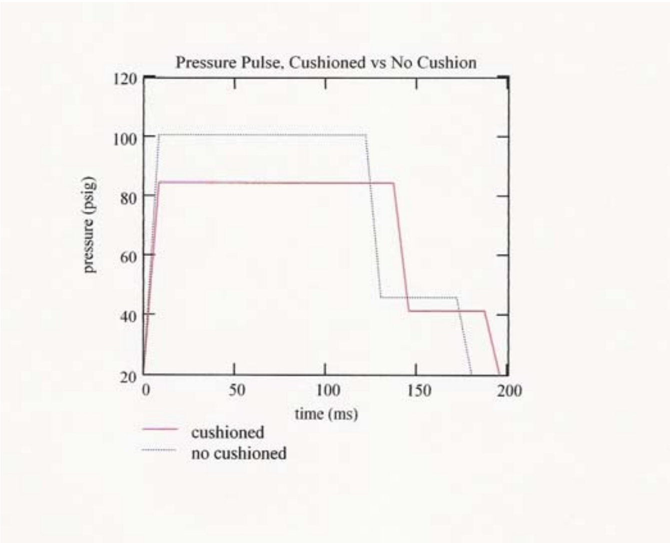
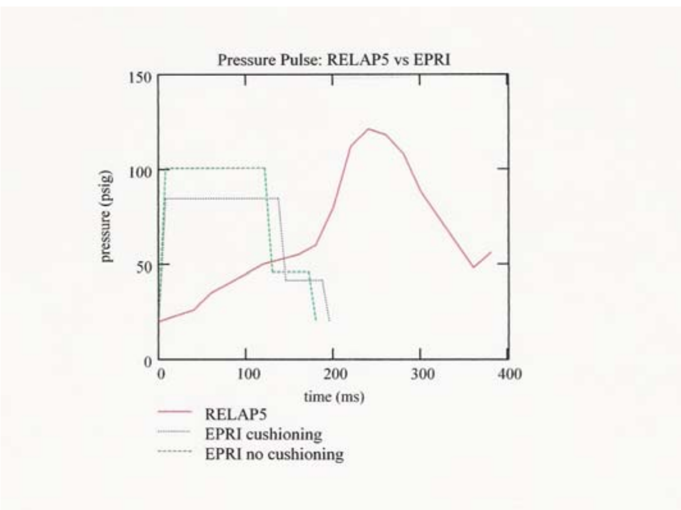
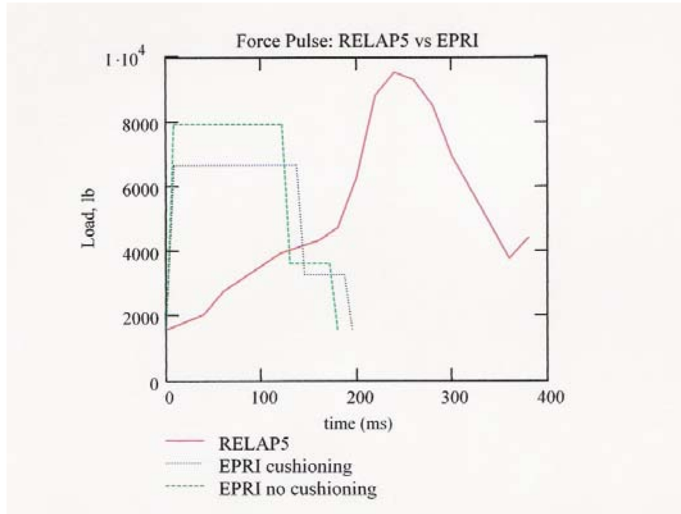


Figure 5 RELAP5 and EPRI Methodology Pressure Pulses



In conclusion, it was determined that the EPRI methodology and the RELAP5 calculations can be used to generate hydraulic loads for the RCFC system. The RELAP5 calculated hydraulic loads for this analysis produced larger loads than the loads developed using the EPRI methodology. The reason that RELAP5 results produced a larger load was due to the

Figure 6 Force Pulse Comparison Using RELAP5 and EPRI



conservative modeling assumptions used in RELAP5. These assumptions were as follows. The SX pump start was assumed to occur in 1 second. The HEM choking model was used sparingly, only enabled at the coil exits and at the transitions from inlet headers to the large bore piping. Only a very small quantity of air was introduced.

ACKNOWLEDGMENTS

We would like to thank Jeff Drowley and Exelon Nuclear for supporting this work.

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3) NUREG/CR-5535/Rev1, RELAP5/MOD3.3 VOLUMES 1 through 8, Prepared by Information Systems Laboratories, Inc., Idaho Falls, ID for Division of Systems Research, NRC, Washington, DC 20555. December 2001.