FEEDWATER HEATER STRING TUBE SIDE ANALYSIS USING PEPSE – A CASE STUDY

David Eder
EXELON
Byron Station
4450 N. German Church
Byron, Il 61010

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Abstract

In February 2003, several Byron Unit 2 feedwater heaters experienced an unexpected temperature transient. Since some temperatures increased, some decreased, no major plant parameters changed (heater drain pump flow, condensate pump flow, generator output, reactor power), and all parameters returned too normal, there was minimum ability to troubleshoot. Additional transients occurred with an increasing frequency during spring of 2003 and were linked to large changes in building temperature. With the additional occurrences, a hydraulic disturbance was the suspected cause. However, without hard evidence, station management did not allow intrusive component troubleshooting. There are no individual condensate or heater drain line flow indications at Byron so the only method of validating the hydraulic transient theory is with heat exchanger inlet and outlet temperature changes. Most hydraulic modeling packages will not model heat exchanger performance so PEPSE was chosen as the modeling package of choice. The site's current PEPSE model was enhanced to more accurately mimic the tube side of the feedwater heaters. This model was used to simulate a variety of hydraulic phenomena and confirmed the suspected degraded component. This proof allowed intrusive component troubleshooting to determine the root cause. The component was repaired during the next refueling outage with no impact on unit operation. This paper will focus on the modeling and methods used to evaluate the hydraulic transient and ultimately determine the degraded component.

Introduction

To thermal performance engineers the following presentation, at first glance, may not appear to be relevant. This presentation does not describe or analyze an event that resulted in Mwe loss. In fact, the following event most likely would never have resulted in any lost generation, no control board alarms, and did not even result in a plant transient that was observable to plant operations. So why am I discussing this today. At the EPRI Thermal Performance Engineer's Conference last year I discussed the attributes of a "Cost Effective Thermal Performance Program". One of those attributes is "Expanding Your Realm of Influence". This fits that classification. But this presentation is not just about expanding your area of influence; it is about solving a plant problem using sound engineering principals and a modeling tool that you are the primary owner's of.

Plant Issue

As part of routine monitoring, Feedwater (FW) heater drain outlet temperatures are trended daily. In February 2003, several Byron Unit 2 feedwater heaters experienced an unexpected temperature transient. This transient occurred slowly over several hours and affected both strings of FW heaters. Some temperatures increased, some decreased, no major plant parameters changed (heater drain pump flow, condensate pump flow, generator output, reactor power), and all parameters returned too normal. In addition, the temperature response between FW heater strings was opposite (for most temperatures that increased on the "A" FW heater string, the same parameter on the "B" FW heater string decreased). The transient nature of the event and no flow indication on any individual drain lines left a minimum ability to troubleshoot. Additional transients occurred with an increasing frequency during spring of 2003 and were linked to large changes in building temperature. With the additional occurrences, a hydraulic disturbance was the suspected cause, but without concrete evidence, intrusive troubleshooting was not allowed on the suspected critical control loop and valves.

Plant Physical Layout

At Byron, there are 7 stages of FW heating, as depicted in the one-line design thermal kit (Figure 1). There are 2 strings of high-pressure heaters (#5-#7) and 3 strings of low pressure heaters (#1-#4). The transients affected the high-pressure heater strings so we will focus on that portion of the system (Figure 2). The #7 FW heater (highest pressure) drains to the #6 FW heater, which drains to the #5 FW heater, which drains to the #5 external drain cooler, which drains to the heater drain (HD) tank. The MSR shell drains also drain to the HD tank. The heater drain pumps take suction from the HD tank, combine into a header where 2 control valves regulate the flow, and discharge into the condensate boost (CB) system. This flow enters the CB system between the #5 external drain cooler and #5 FW heater. In addition MSR second stage reheater drains enter the #7 FW heater and MSR first stage drains enter the #5 FW heater. There are no individual line flow indications. At full power, HD tank temperature is 342 F and the outlet of the #5 drain cooler is 325 F. During the temperature transients, the 5A FW heater inlet temperature increased and the 5B FW heater inlet temperature decreased. Since these temperatures moved in opposite directions, it was suspected that the HD tank flow control valves were moving in opposite directions during the transients. However, since both valves get that same control signal and the transients appeared to be temperature related, a failure mode was not readily apparent.

Analysis Methods

Drain Cooler Heat Balance Calculations

The first attempt to determine if changes in HD flow split could be the cause of the observed temperature changes was to perform heat balance calculations on the #5 external drain coolers. All drain cooler inlet and outlet temperatures are known and it is assumed that the tube side flow (condensate boost from the CB pumps) is evenly split between the two strings. The expected result was a decrease in calculated drain flow on the "A" string of heaters (since the overall string temperature rise decreased due to the increase in inlet temperature) and an increase in calculated drain flow on the "B" train of FW heaters (since the overall string temperature rise increased due to the decrease in inlet temperature). In addition, the calculated MSR shell drain flow (total HD pump flow minus the "A" and "B" heater string calculated drain flows) should remain constant. The actual trend of calculated drain flow during the transient went opposite of expected and there was a change in calculated MSR shell drain flow. The change in calculated MSR shell drain flow suggested the calculation of heater string drain flow during the transient was inaccurate because a change in MSR shell drain flow could not be theorized as being related to the non-symmetry in the FW heater strings.

PEPSE - HD Flow Split Only

The second attempt to determine the cause of the temperature swings was to utilize the site PEPSE model. The site's PEPSE model already included multiple strings of FW heaters, all FW heaters in simplified design mode, and a full array of emergency drains and auxiliary components. When a simulated HD flow split was run, the results still did not match the plant. There was an increase in drain flow from the "A" train drain cooler (which did not match expectations), and the various FW heater inlet and outlet temperature changes did not match the plant very well. However, the MSR shell drain flow was constant.

PEPSE – Tube Side Model Developement and Analysis

After some thought, it was suspected that the assumed 50/50 CB flow split into the high-pressure heater strings during the transients was not correct. However, there was no method to directly prove or disprove this theory. Since the entry and discharge from the high-pressure heater strings are from common headers, the fluid pressure at these points must be the same. If the CB flow split is 50/50 and the HD flow split is 60/40, the end result would be a lower outlet pressure on the heater string with more HD flow. Since this cannot happen, it was theorized the heater string with the higher HD flow would have the lower CB flow and vice versa. So, if the component pressure drop characteristics are known, the HD and CB flow splits can be adjusted so the outlet pressure of the heater strings are the same. This will provide an array of possible flow splits. The likely correct flow splits will most closely match all the FW heater inlet and outlet temperature changes observed in the plant.

Several adjustments to the PEPSE model needed to be made to perform the required analysis and some plant data needed to be collected to validate and tune the model. First was plant data collection. Several years ago the #5 drain cooler tube side pressure drops were collected. This data was evaluated and closely matched the vendor predicted tube side pressure drops. Thus it was assumed all FW heater tube side pressure drops also matched the vendor predictions as listed on the FW heater data sheets. A precision Heise pressure gauge was used to obtain the CB header pressures before and after the high-pressure heater strings. This was not exactly possible due to the available location of pressure taps, but it provided reasonable numbers and was used as is.

The PEPSE model required some minor changes & tuning and is described next. The existing site PEPSE model was a fairly detailed model. It already contained all parallel strings of components (3 strings of LP FW heaters & turbines, 2 strings of HP FW heaters), the FW heaters had been placed in simplified design mode, and several other features were already incorporated. Although the FW heaters were in simplified design mode, the tube side pressure drops had never been verified against the FW heater data sheets. Some minor differences in the PEPSE data were observed and were corrected by adjusting the FW inlet and outlet nozzle sizes. Each of the streams connecting the FW heaters were changed to Stream type 1 components and the pipe ID, approximate pipe lengths, and "Moody f" (Moody Friction factor obtained from a Crane Hydraulics book) were entered. The final stream also included the elevation difference between the FW header pressure measurements obtained from the plant. The model was run and the stream "Moody f" factor was adjusted to match the actual header pressures obtained from the previous plant measurements.

This completed the model development and tuning. Next, was the determination of the possible flow split percentages. This was performed in an iterative process. First a HD string flow split was chosen (for example 60/40) with the CB string flow split at 50/50. A PEPSE run was performed and the heater string outlet pressures were recorded. As expected, the "A" high pressure FW heater train had a lower outlet pressure (since it had the highest flow). A series of runs were performed with various CB flow splits until the heater string outlet pressures matched. This yielded a HD and CB flow split that is possible based on the hydraulic analysis. A different HD flow split was chosen and another set of PEPSE runs were made to determine the corresponding CB flow split that resulted in both FW heater strings having the same outlet pressures. This was done for several different HD string flow splits until a PEPSE run matched the plant conditions for #5 FW heater inlet temperature changes. This parameter was chosen because it observed the largest change during the transients. This represented the most likely flow split combination observed in the plant. The result of this PEPSE run was compared against the plant data for all FW heater & drain cooler inlet and outlet temperature changes observed during the transients. All the observed FW heater temperature changes matched those modeled by PEPSE. Additionally, the changes in heater string drainage flow predicted by PEPSE matched the expected change and MSR shell drain flow remained constant.

The CB flow split data was then entered into the drain cooler trending spreadsheets. The changes in calculated drain flows matched those predicted by PEPSE and the MSR shell drain flow remained stable during the transient as was expected. This analysis validated the hydraulic transient theory based on the FW heater tube and shell side data. The information was presented to management and intrusive component troubleshooting was approved. The degraded component was determined, work orders were generated, and the work was SCARFed into the upcoming refueling outage (2 months away). Following the refueling outage, the transient changes in #5 FW heater inlet temperature were gone.

Summary

Although the main use of PEPSE is thermodynamic modeling and analysis, it can be used to evaluate some hydraulic phenomena when heat exchanger performance data is available. To perform this analysis a detailed PEPSE model is essential. A detailed model must include; multiple strings of components, FW heaters in simplified design mode (at a minimum), turbine extraction pressures from mass flow, and appropriate component pressure drop estimates. Although I was able find a solution by performing this analysis manually in an iterative nature, it is suspected that a higher level PEPSE user could set up the required analysis to be performed semi-automatically. As thermal performance engineers we have access to a powerful modeling tool that can be used to solve more than just Mwe issues. In this day of shrinking resources, this is an excellent opportunity to "Expand Your Realm of Influence" to solve plant problems.

Figure 1

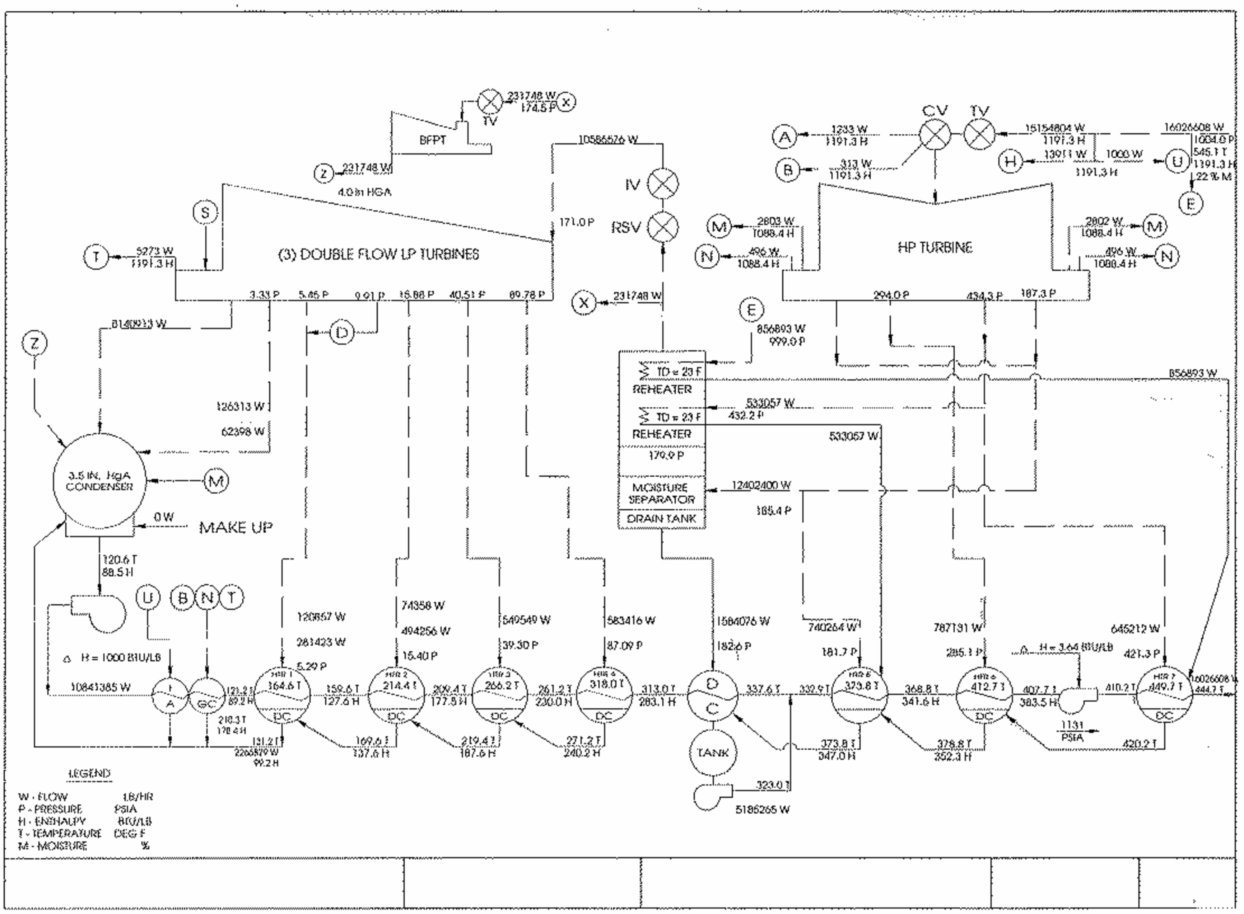

Figure 1 - Plant Heat Balance

Figure 2

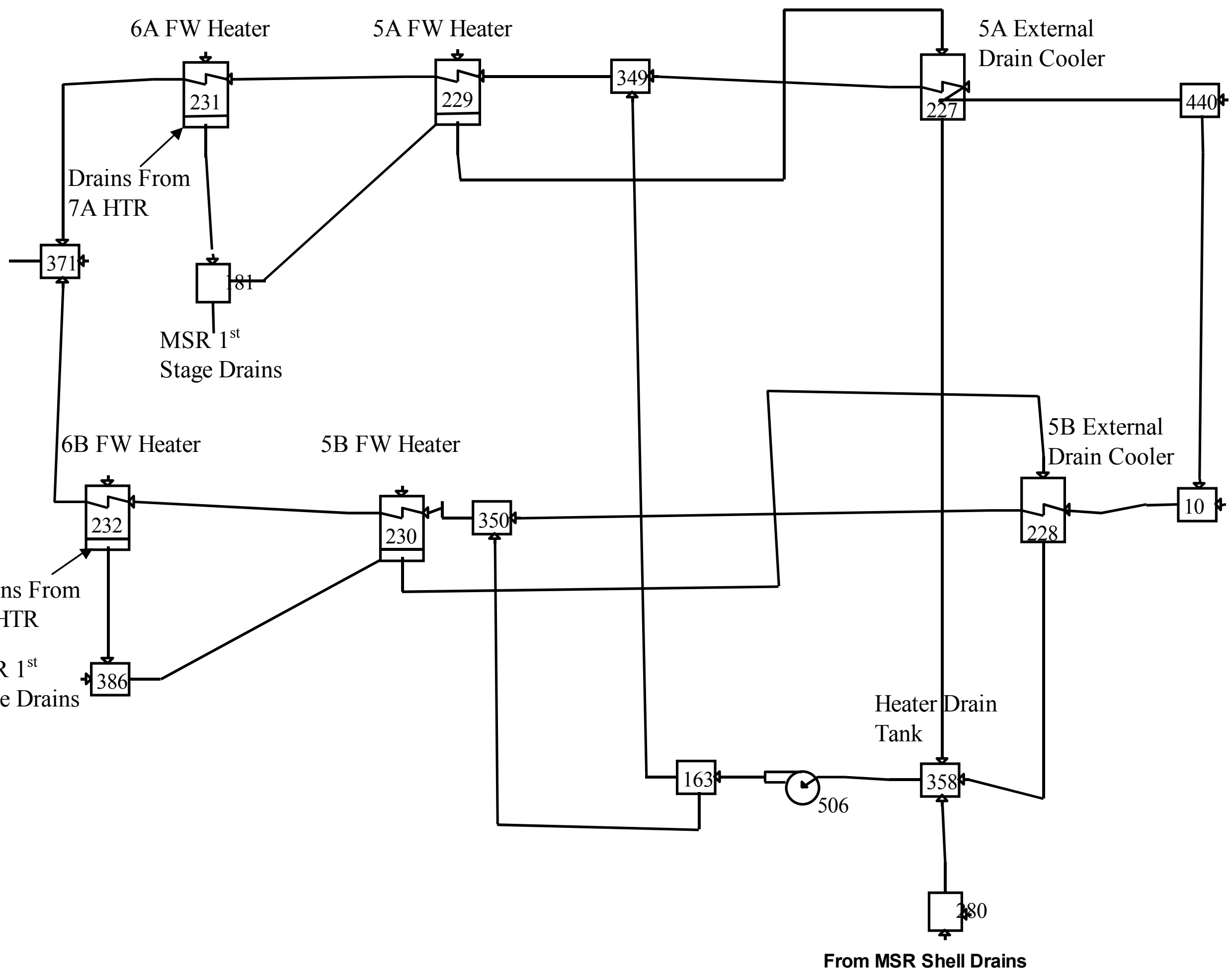

Figure 2 - High Pressure Heater String Layout