“OPERATIONAL ISSUES RELATED TO DEGRADED AND UNRELIABLE FEEDWATER HEATERS”

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Introduction:

This article discusses considerations for imposing operating limitations and guidelines upon feedwater heater (FWH) systems when one or more FWHs are severely degraded or completely removed from service. FWH manufacturers are typically requested to design FWHs to meet a specified design point which is usually referred to as the performance guarantee. Operation at this design point constitutes normal operation, and the steam, feedwater, and drains flows at this point are called normal flows. However, since power producing steam units are seldom operated at the exact design point, FWH manufacturers should also be required to check the equipment design for safe, non-failing operation across the full range of load impositions, including the worst anticipated abnormal or overload conditions. It is the Utility engineer’s responsibility to identify and quantify these potentials as an integral part of his technical specification. Essentially, the FWH should have the conservatism and capacity to safely handle the abnormal flows without damage to the equipment for the duration of the abnormal condition; otherwise, additional operational limits may need to be imposed.

Analyze the Configuration of Associated Systems:

Based on today’s state of the art, utilities purchase replacement FWHs that require the capability of carrying the overloads that are typically caused by increased feedwater flows as a result of an out of service parallel string, and/or lower inlet feedwater temperatures due to the isolation of the next upstream (lower-pressure) FWH or string of heaters. This requires evaluation and analysis of the configurations and arrangements of the allied systems associated with the specific Units’ feedheating system, i.e., extraction steam, feedwater, and drains and venting systems. By examining the potential effects of the worse hypothetical operational mode, the specifying engineer can give the heater manufacturer the information needed to assure that the design will be robust enough to handle this abnormal overload potential. However, additional analysis may be required to quantify these abnormal conditions, especially if the plant has no historical operating data at these modes of operation.

In trying to extend the life of older FWHs that may not have been purchased with today’s conservative design margins, Utility engineers are challenged with the determining the operational margins that may be available. However, even with the best plans in place for older or newer FWHs, extraordinary conditions may occur where larger flows are encountered and satisfactory operation is difficult to obtain unless proper provisions have been made in the operation of the plant. The operation of severely degraded FWHs and/or the removal of various numbers of FWHs from service during unit operation are of special concern in this regard.

Principals of Closed FWH Operation:

It is important to understand how heaters will react to changes in their input operating conditions. The heat transfer relationship of a closed feedwater heater is based on achieving a thermodynamic balance between the heat given up on the shell side being equal to the heat picked up by the feedwater flowing inside the tubes. The energy transferred via the condensation of the extraction steam, added together (where applicable), with the energy of the incoming cascading drainage flow from the downstream heater, thermodynamically balances with the temperature rise of the tube side feedwater flow. The understanding that all operating closed FWHs will seek to satisfy this basic thermodynamic heat balance, helps us appreciate the fact that FWHs will destroy themselves trying to satisfy thermodynamic equilibrium.

Operational Impositions on the Turbine, Boiler, and FWHs:

If a FWH (or group of FWHs**)** is bypassed, the feedwater will enter the next stage FWH at a colder temperature, and that FWH will extract additional steam. Overloading up to 300% of design steam flow has been experienced. Large steam flows and the resulting high drains flows can do catastrophic damage to the FWH from flashing two-phase flow, tube vibration, erosion, etc. To avoid this damage, the changes in flow that will be needed to ensure proper velocities and reasonable pressure drops through all zones of the remaining FWHs must be carefully analyzed. At the same time, it is important to remember that limitations for the turbines and boilers must also be considered.

The turbine is affected when some FWHs are not operational, since steam will not be extracted from all the required stages, thus creating an imbalance in the turbine. However, recommendations for reduction of load with any and all combinations of FWHs out of service can and should be obtained from the turbine manufacturer to remedy this situation.

Restrictions are also present in the boiler. If the temperature of the feedwater at the economizer inlet drops too low, the economizer might suffer thermal shock or the boiler could be fired too hard, creating problems in the superheating tubes as well as in the boiler wall tubes. Again, the boiler manufacturer should supply information stating the minimum feedwater temperature that can be tolerated by the boiler, and any other limitations which may apply. Figure 1 is an example of the reply received by one utility upon making such a request. The specific boiler in question was designed to receive feedwater at 530^{o}F at 100% power. The vendor recommended a minimum feedwater temperature of 350°F to avoid thermal shock to the economizer. To prevent damage to the superheat tubes, it was also recommended that during periods of reduced feedwater temperature, the boiler should be operated at or below the appropriate line on the graph. For example, if feedwater temperature was reduced to 423^{o}F, and it was desired to fire the boiler at 70%, it would be necessary to accept a decrease in superheat of 60^{o}F below the designed value. Conversely, with a 60^{o}F reduction in superheat, the boiler should not be fired above 70%. Thus, it is apparent that communication between utility engineers and vendors is essential in prolonging the service life of not only the FWHs but also the other major components in the system.

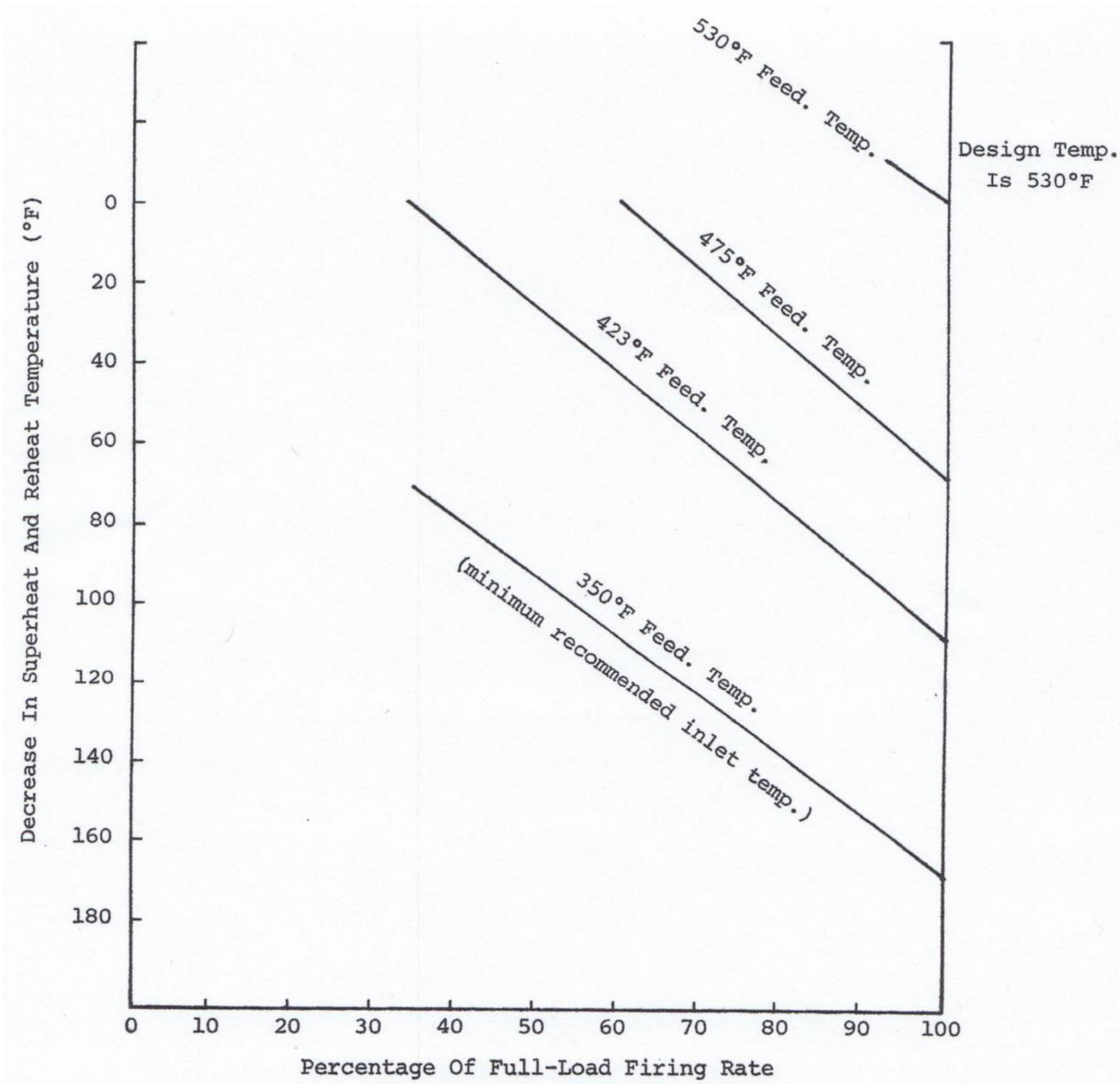

Figure 1 – Limitations on Feed Inlet Temperature based on Load

A particularly poor practice occasionally used in some plants is to achieve higher megawatt output from the plant by cutting out the high-pressure (HP) FWHs and overfiring the boilers. Unless the plant was specifically designed for this type of abnormal overload (which is unlikely), the operator is exposing the boiler to thermal shock, while overloading several turbine stages and the remaining FWHs. The degraded heat rate that results may be acceptable for load dispatch reasons, but the eventual cost in permanent system damage could be very high.

<u>Examples of How to Determine Operational Limitations:</u>

This section presents two specific examples from the same utility plant in which a number of FWHs were removed from service for repair and discusses the rationale used in determining the proper operating conditions. In each case, the unit in question was capable of generating 326 megawatts (MW) (net) at 100% Load.

Case 1**,** as shown in Figure 2, displays a schematic of a two-string (A and B), eight-FWH (1-8) unit. FWHs 1-6 are considered low-pressure (LP) FWHs; while FWHs 7 and 8 are the HP FWHs. HP FWHs 7A and 8A were to be removed from service for repair. To ensure safe operation of the remaining FWHs during repairs, without shutting down the plant, the following measures were enacted.

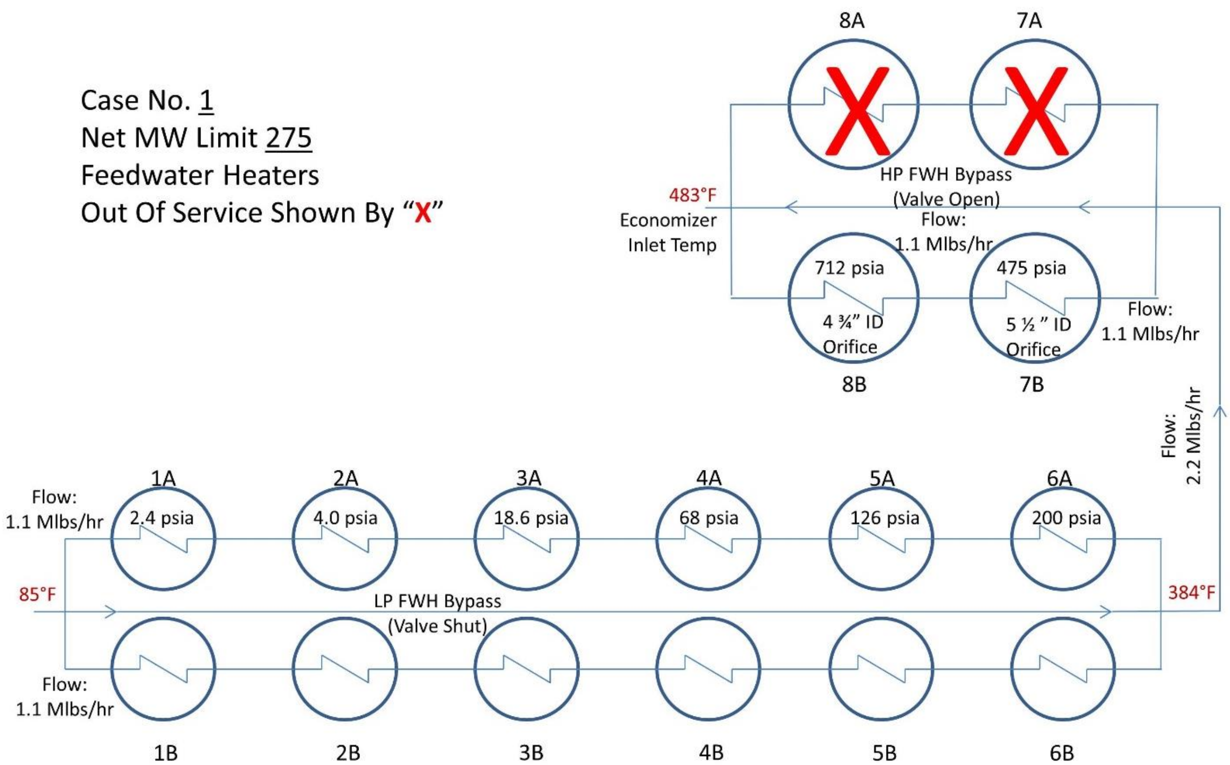

Figure 2 – Operating Limits and Guidelines for Case 1 – Loss of HP FWH String "A"

First, predictive performance calculations to correct heater design values to actual operating data were performed in accordance with principles of ASME Code PTC-12.1. This off-design model provided a sanity check to confirm that any degradation in heater performance was attributed to the current as plugged condition. Then the turbine manufacturer was consulted in an effort to determine the required reduction in load due to possible turbine limitations. The manufacturer stated that when two HP FWHs from one string are cut out, the steam flow can be throttled to a maximum of 2,220,000 lbs/hr without detriment to the turbine parts. Normal flow for this plant at 100% load would be 2,300,000 lbs/hr.

Having acquired the turbine limits for flow, the next step was to analyze the limitations of the FWHs themselves. Helpful in this effort was information concerning the operating history of each FWH. Information such as the age of the FWH, tube material, the number of tubes plugged, condition of the tubes and other components and performance test data (terminal temperature difference, and drains approach temperatures) is invaluable when evaluating FWHs for their ability to handle load. In Case 1, the utility engineer was aware that FWHs 7B and 8B had already deteriorated due to erosion at the inlet end and pitting with as much as a 50% wall reduction was present in many tubes. This condition required additional load restrictions. He then went through an iterative process to derive what those limits should be. Assuming a flow of 2,200,000 lbs/hr to the boiler to be acceptable, this flow was assumed to split evenly between the two strings of FWHs. By the time the feedwater exited from the LP FWHs, it had attained a temperature of 384^{o}F at a shell side pressure of 200 psia. As before, half of the flow (1,100,000 lbs/hr) continued on to the inlet of the B string HP FWHs; however, the remaining flow was directed through a bypass line because HP FWHs 7A and 8A were inoperative. Because of the aforementioned deteriorated tube condition of HP FWHs 7B and 8B**,** a judgment was made to limit the velocity through the FWH to 6 feet per second (ft/sec.). This measure would prolong the life of the tubes. Since each HP FWH had a different number of tubes plugged, they had to be individually analyzed. From flow calculations performed on FWH 7B**,** it was determined that the maximum flow that could be allowed through the tubes and still maintain a velocity of 6 ft/sec was 500,000 lbs/hr. It is noteworthy that by reducing the feedwater flow, the steam quantity extracted on the shell side was also limited. Reducing steam quantities automatically reduces the velocities in the desuperheating and subcooling zones, which also prolongs FWH life.

Therefore, provisions were made to bypass the remaining 600,000 lbs/hr through an internal orifice made in the partition plate on the channel that was sized by using a standard equation. The purpose of the orifice was to divert some of the water from the tubes and to provide an opportunity for mixing the water at the outlet of the FWH. In this way, the amount of overloading on a FWH can be limited, thus prolonging its life. Similar calculations were performed for FWH 8B, which showed that only 450,000 lbs/hr needed to be bypassed through an internal orifice.

By limiting the efficiency of the FWH strings, which must be done to preserve the life of the FWHs, it is important to consider what the effects will be on the boiler. As can be seen in Figure 2, the temperature at the economizer inlet was 427^{o}F, whereas the normal inlet temperature at 100% load was 530°F. Correspondence with the boiler manufacturer indicated that 320°F was the minimum temperature that should enter the boiler; therefore, the boiler did not place any restrictions in this case. However, from the graph shown in Figure 1, which was supplied by the boiler manufacturer, it can be seen that at 427^{o}F and 100% load, there is approximately a 110°F loss of superheat. This information must be relayed to the turbine manufacture, who will determine if the loss will be detrimental to the turbine. For Case 1, this did not present a problem; therefore, the 15% load restriction was imposed to prevent further deterioration of the FWHs. From Figure 2, one could determine the megawatt net generated with the calculated parameters, which in this case was 275 MW. Therefore, generating 275 MW with two HP FWHs removed from service should not further degrade the equipment.

Case 2 (Figure 3) presents the dramatic example of all of the LP FWHs from both strings being removed from service. Although losing both LP strings at the same time seldom happens, this situation can occur when the ability to bypass individual FWHs is non-existent. One leaking LP FWH can force the removal of a11 the LP FWHs in that string from service.

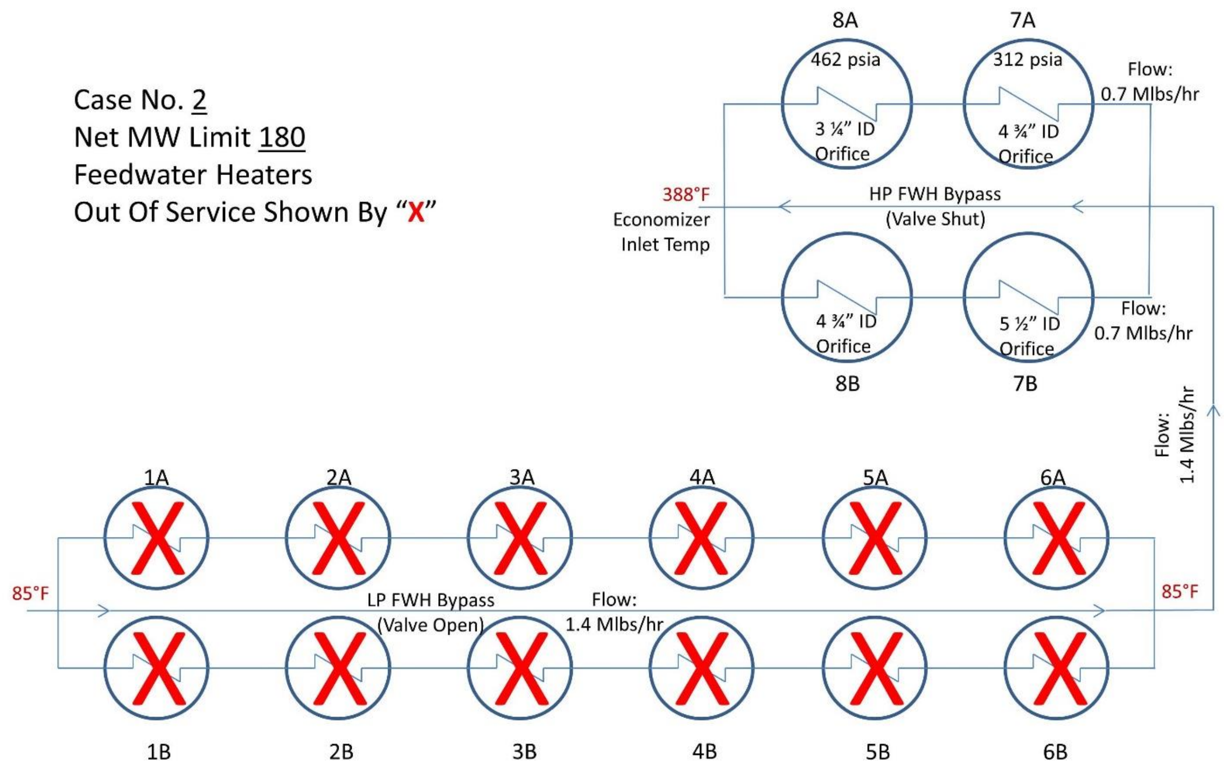

Figure 3 – Operating Limits and Guidelines for Case 2 – All LP FWHs Out of Service

Case 2 (Figure 3) was handled in the same manner as Case 1. The turbine manufacturer indicated that for this condition there was no need to limit feedwater flow; therefore, the plant engineers analyzed the FWHs themselves. It was readily apparent that even healthy HP FWHs would not be adequate to handle the increased load. Again, these FWHs were already deteriorated to the extent that internal orifices (Figure 4)were installed to bypass some of the flow. Having already dealt with Case 1 as well as a variety of other cases of degraded operation enabled the support engineer to quickly estimate the overall reduction in feedwater flows that would be necessary to permit safe operation of the remaining FWHs. To verify that these estimates were correct, he performed the calculations already outlined in the previous example to ultimately arrive at an economizer inlet temperature of 388^{o}F and a flow that was throttled to 1,400,000 lbs/hr. For this set of parameters, the boiler does not impose a reduction in load, although there will be a corresponding loss of superheat of approximately 140^{o}F. A consultation with the turbine manufacturer resulted in the determination that the loss of superheat at that rate of steam flow did not necessitate a turbine restriction. Again, it is emphasized that if limitations were not imposed on the operation of the HP FWHs**,** they would have quickly deteriorated, condemning the plant to potential forced outage(s). Serious damage to the boiler would have been the result of operation without any FWHs. Many boiler failures can be ascribed to operation in this manner.

The use of the above examples is not intended to be a blanket endorsement of the use of internal orifices to limit flow through degraded FWHs. In the case cited, this particular solution was implemented after careful analysis as a temporary improvement to a bad situation.

These cases vividly illustrate the type of limiting operational guidelines that can be dictated by the removal of FWHs from service. By considering the protection of the turbine, boiler, and

FWHs simultaneously, it is possible to attain the highest reasonable power output without destroying equipment in the process.

Figure 4 – Typical Orifice drilled in FWH pass partition plate