Common Problems in Feedwater Heaters

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INTRODUCTION

What are the common problems in Feedwater Heaters?

• Vibration damage
  • Wear at the Tube Support Plates
  • Tube-to-Tube Wear mid-span
  • Fatigue failures at either
• Steam erosion of the tubes, tube support plates and/or the shell
• Steam erosion / by-pass at the drain cooler end plate
• Liquid level control –
  • Too low and steam is allowed into the lower pressure drain cooler and two phase flow can result which can cause severe damage
  • Too high and not only is there thermal performance lost but the liquid can flash to steam releasing high energy or deflect the steam into the tubes causing vibrational failures
INTRODUCTION

What are the common problems in Feedwater Heaters?

- Broken, failed or inadequate steam impingement plates
- Broken, eroded or failed TSP tie rods
- Broken, eroded or cracked partition plates
- Foreign material or loose parts in the shell side or tube side
- Stress Corrosion Cracking in the roll transition / tubesheet crevice in high temperature / high pressure FWH’s
- Failures due to Denting from operation, transport and/or manufacturing of the FWH
- Leaking or loose tube plugs
- Vent channel erosion can lead to tube failures
INTRODUCTION

What can be done to reduce the chance of FWH leaks?

- A risk based ET inspection schedule that will identify the problem before it becomes a BIG problem.
- Review of the ‘as built’ design drawings to identify potential problem areas to be sure they are inspected if the current program is not a 100% inspection plan.
- Modify the ET inspection technique to be sure the potential problems can be identified.
- If erosion or vibration damage is found in the drain cooler talk to Operations and the FWH system engineer to review level control variations and verify the level control is functioning properly.
- If failures are occurring at the DC End Plate look for erosion of the hole and possibly expand and/or sleeve the tubes to get better sealing and change the local vibration characteristics.
- If erosion is identified at the TSP’s then be sure to UT the shell and conversely, if UT identifies shell erosion be sure to have the vendor look close at the TSP’s.
- If denting is suddenly occurring or growing at the TSP’s perform an axial measurement of the locations of the TSP’s to see if they are moving and/or locking the tubes.
INTRODUCTION

What can be done to reduce the chance of FWH leaks? (cont’d)

• Perform ‘as found’ inspections when the channel head and partition plate(s) are removed for Foreign Material or loose parts on the tube side and be sure your vendor is looking for and reporting them on the outside of the tubes.

• If there is suddenly erosion, vibration, denting or what appears to be a loose part where the impingement plate is expected to be then perform a video inspection of the area to be sure the plate has not broken loose.

• Check the venting to be sure it is functioning properly.

• It is reported that some utilities puncture the tube prior to plugging it to remove the possibility of pressure build up and ejecting the plugs and/or stabilizing cable into the channel head.

• Stabilizing cables can be used to prevent tubes that sever from flailing.

• If FWH replacement becomes the only option perform an in-depth analysis of exactly what caused the failure and be sure to compensate for that in the new FWH design but be careful not to create another problem with the change. Consult with FWH design experts to discuss the possibilities.

• EPRI is currently working on a “HX Design Specification Guide” which may add some insight of what to ask for and expect to receive.
Feedwater Heater Design

- Feedwater heater design has been relatively unchanged for many years. There are three basic types:
  - Single zone – condensing zone only
  - Two zone – condensing and drain cooling zones common to lower pressure lower temperature nuclear steam cycles
  - Three zone – de-super heating, condensing and drain cooling zones – mostly found in higher pressure and higher temperature fossil steam cycles

- The main differences in FWH’s are due to overall costs and the lower the cost the more chances of future design/material problems
Feedwater Heater Design

In the old days the S/G and FWH’s were combined.
Feedwater Heater Design

This is a three zone FWH. The steam first enters the de-superheating zone, then passes to the condensing zone and changes liquid and then out through the drain cooler zone.
Feedwater Heater Design

It is not clear if this is a two zone or a single zone but this illustrates the condensing zone of a large FWH with 3 extraction steam inlets.
Feedwater Heater Design

This is what is called the skeleton. The tube supports and tie rods are visible and the tubes should be inserted shortly.
Feedwater Heater Design

New U-tubes in Mill After Electric Annealing
Feedwater Heater Design

This would be a very small FWH but the segmented tube supports/baffles are clearly visible while the tube insertion is in progress. The segmentation is for cross flow for more efficiency. Note the ½ holes only make 180 degree contact in the overlap area.
Vibration Damage

There are two basic types of vibration damage in FWH’s:

1) Vibrational wear at Tube Support Plates
Vibration Damage

There are two basic types of vibration damage in FWH’s:

2) Tube-to-Tube vibrational wear at mid-span
Vibration Damage

Area of tube leaks and inspection results in lower left corner. The damage was located in the condensing zone below the extraction steam inlet.
Vibration Damage

The ‘dry’ tube ends were the nine leakers. The plant had been at low power so the tubes that were open to steam side dried and became very easy to identify.
Vibration Damage

The suspected leakers (dry tubes) were inspected with a video probe to identify the nature of the damage and its exact location.

They were severed at approximately 15’3” from the tubesheet in the condensing zone.
Vibration Damage

In this photo, vibrational wear at a TSP is visible.

Due to the limited ET inspection scope, it could not be determined if Tube-to-Tube wear was also present, but given the complete failures, it was likely and collateral damage was occurring.
Vibration Damage

This was part of the ‘as built’ design drawing and notice the extraction steam inlet located near the middle of the heater and at 45 degrees to the left of center which is also the side where the leakers were located. The steam would enter and travel down the left side and deflect off and/or flash the liquid level at approximately the bottom row of tubes and up into the tubes in the area of the leakers causing severe vibration damage.
Vibration Damage

A Cad program was used to illustrate the damage areas in this FWH and help identify what the mechanism was.
**Typical Damage Mechanisms – Tube-to-to-Tube Wear**

**TUBE-TO-TUBE VIBRATION CALCULATION**

\[ L_C = 9.5 \left( \frac{EI}{\rho V^2 D} \right)^{1/4} \]

- **E** = Modulus of elasticity of the material, psi
- **I** = Tube cross section moment of inertia, in\(^4\)
- **\(\rho\)** = Steam density, lb/ft\(^3\)
- **D** = Tube O.D., in
- **V** = Turbine exhaust flange continuity velocity, ft/sec
- **L\(_C\)** = Critical unsupported length, in

For brass **E** = 16 x 10\(^6\) for stainless **E** = 28 x 10\(^6\) for titanium **E** = 14.9 x 10\(^6\)

The value of "E" for various alloys is very significant.
Typical Damage Mechanisms – Tube-to-to-Tube Wear
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Typical Damage Mechanisms – Tube-to-to-Tube Wear
Erosion of Internals

Steam flow can erode away the carbon steel tube support plates while leaving the stainless steel tubes undamaged. However they are then unsupported which can lead to failures from fatigue and/or vibrational damage.
Erosion of Internals

Area of TSP erosion. Note the large gaps between the tubes and the TSP holes.
Erosion of Internals

Area of TSP erosion. Note the large gaps between the tubes and the TSP holes.
Erosion of Internals

Actual eroded DCEP holes. Note the large gaps between the tubes and the holes.
Erosion of Internals

Drain Cooler, End Plate, Shroud, Inlet Snorkel
Erosion of Internals

So maintaining level around the bottom row of tubes keeps the snorkel submerged and reduces the chances of two phase flow.
Erosion of Internals

View of a thick (~3”) Drain Cooler End Plate
Erosion of Internals

Showing back face of tubesheet of a higher pressure FWH with a small Drain Cooler.
Erosion of Internals

View of Tubesheet showing a separate Drain Cooler Section.
Erosion of Internals

View from U-Bend end with tubes installed showing the separate DC and the end of the full length Shroud.
Erosion of Internals

Prebuilt Drain Cooler Shroud showing the Inlet Snorkel.
Erosion of Internals

View showing vent channel and vent line.
Erosion of Internals

View of vent channel.

That is why there are ‘blank’ areas in the tubesheet to allow for the channel to run through the length of the FWH.
Erosion of Internals

View of full tube support plate for the condensing zone, tie rods with protective coverings and vent channel
Erosion of Internals

A FWH that has been in service and the venting line has been eroded completely so NO effective venting.
Erosion of Internals

- Extraction Steam
- Impingement Plate
- Eroded Tie Rod
- Broken Welds
Erosion of Internals

ECT Analysis response to a nominal TSP

Nominal TSP set at 10 volts vert max on low frequency Absolute process channel and set to low span to allow vertical TSP signal to be viewed on strip chart.

Notice the smooth transitions of TSPs.
Erosion of Internals

ECT Analysis response to an eroded TSP.

Note the smaller TSP signal and the deposit signal indicating the build up of CS deposit left from the erosion.

Deposit signal on one side of TSP indicating down stream flow direction

Small distorted TSP signal
Erosion of Internals

Horizontal U-Tubed single zone FWH with extraction steam inlets at 12 o’clock.

The red tubes indicate tubes recording possible TSP degradation while the blue tubes were inspected with no damage of any type recorded.
Erosion of Internals

Cad drawing showing the locations that recorded erosion of TSPs
Erosion of Internals

Tube-Pro 3D Modeling

Tubes with TSP Degradation Identified on Tubesheet
Erosion of Internals

Tube-Pro 3D Modeling

Locations at Tube Supports that indicated TSP Degradation
Erosion of Internals

Tube-Pro 3D Modeling

Close up of area showing TSP Degradation
Liquid Level and Steam By-pass into Drain Cooler

The drain cooler is lower pressure than the condensing zone so the liquid level must be kept above the drain cooler inlet snorkel. The normal level is just below the bottom row of tubes. If the level drops then steam is allowed into the drain cooler it will flash liquid to steam (two phase flow) releasing energy and causing vibrational damage and/or erosion of the TSP/baffle plates.
Liquid Level and Steam By-pass into Drain Cooler

Example of erosion of Tube Support Plates out in the condensing zone.
Liquid Level and Steam By-pass into Drain Cooler

Erosion of Tube Support Plate / Baffle in Drain Cooler

Drain Cooler Zone (Shroud Removed)
Tubesheet End
Unit Inverted
Condensing Zone

Segmented TSP's
Eroded TSP
Drain Cooler End Plate
Liquid Level and Steam By-pass into Drain Cooler

Actual ET results utilizing general voltage percent analysis technique

Actual removed TSP from Drain Cooler
Liquid Level and Steam By-pass into Drain Cooler

Remnants of TSP ligaments that can give small but false signals of supports
Feedwater Heater Drain Cooler End Plate

The drain cooler end plate is normally much thicker (2.0” – 4+”) than the tube support plates (0.625” – 0.750”) and liquid between the tube and hole acts as a meniscus to seal the pressure differential. In some cases the FWH manufacturer actually expanded the tube at the Drain Cooler End Plate (DCEP) to get a better seal. Sometimes this could lead to failures from cracking because the tube could become locked and not allow thermal expansion.

If steam bypasses through the tube hole in the DCEP the tube hole can erode and become larger allowing more steam bypass. If expansion of the tubes in this location is planned then Array Probe ECT should be used to determine if the tube holes have an smooth edge or have been eroded to a knife edge which could lead to future problems.

The expansion process is usually until the tube makes contact and then released so the tube rebounds slightly so it does not lock in place like a tubesheet expansion thus allowing thermal expansion.

The following examples illustrate ECT indications that could be developing cracks which were pre-emptively plugged.
Feedwater Heater Drain Cooler End Plate

This is an ET graphic of Tube #1-3-23 showing a DCEP with only a slight expansion.
Feedwater Heater Drain Cooler End Plate

This is also an ET graphic of Tube # I-3-23 showing the expected expansion was placed beyond the DCEP.
Feedwater Heater Drain Cooler End Plate

This is an ET graphic of Tube # I-29-16 showing a DCEP with a distorted expansion indicating a possible crack.
Feedwater Heater Drain Cooler End Plate

This is an ET graphic of Tube # 1-30-5 showing a DCEP with a distorted expansion indicating a possible crack.
Feedwater Heater Drain Cooler End Plate

This is an ET graphic of Tube # I-30-6 showing a DCEP with a distorted expansion indicating a possible crack.
Feedwater Heater Drain Cooler End Plate

This is a bobbin probe ET graphic of a Tube showing a DCEP with a distorted expansion indicating a possible crack.
Feedwater Heater Drain Cooler End Plate

This is an array probe ET graphic of the same Tube showing a DCEP with a crack indication.
Feedwater Heater Drain Cooler End Plate

If there are failures at the DCEP then prior to performing any expansion as a repair the following is recommended:

1) Determine the condition of the DCEP with an Array ET probe (square or knife edge).

2) If the hole surface is conducive (not knife edge) then expand the tube to make a better seal.

3) If vibration / fatigue damage was present prior to expansion, consider inserting a sleeve which would be seal rolled to the parent tube. This not only provides a secondary boundary in case the parent tube fails but also would change the vibrational resonance of the tube with in that immediate area which may mitigate any vibrational / fatigue problems.
Feedwater Heater Drain Cooler End Plate

If there are failures at the DCEP then a couple of concerns are:

1) The reported thickness (1.250”) of the DCEP seems rather small to start with.

2) The T-304SS tube wall thickness (0.028”) also seems rather thin and the resonance value may be conducive to vibration especially if power uprates have been performed which could lead to flows above original design factors.

3) A good understanding of the hole surfaces and diameters needs to be developed so the tube is not expanded out to a sharp contact edge and/or the tube wall thickness is not reduced much more to seal an enlarged tube hole. The actual design / ‘as built’ drawings should have the original hole diameter listed.
Feedwater Heater Drain Cooler End Plate

While this is an example of erosion of Tube Support Plates out in the condensing zone this illustrates how much area could need to be filled with expansion thus reducing the tube wall thickness greatly.
Broken or Inadequate Impingement Plates

The area of plugs along the top were from severe steam erosion next to the edge of the impingement plate.

The red tubes in the base were from loose parts TS damage.
Broken or Eroded Tie Rods

The tie rods that hold the TSP’s in place during assembly are usually mild steel threaded rods with nuts welded in placed on both side of the TSP’s. They help to position the TSP’s square to each other so the tubes can pass fairly easily through the tube holes. To protect the mild steel rods from the steam flow they are typically covered with a piece of stainless steel tube. If conditions are unfavorable during operation the SS covering can erode and then the mild steel rod will go next. This can allow the TSP to move in some locations and potentially lock or bind the tubes during thermal expansion. They can also cause denting when they move.

Broken tie rods have also been found in FWH’s that was attributed to improper operation. They were heated up to quickly during start-up and cooled down to quickly during shut-down. This caused tubes to become locked at the TSP’s and can lead to stress cracks in un-annealed U-bends.
Broken or Eroded Tie Rods

The tie rod is severely eroded but has not failed at this time. The TSP in this same location has been completely eroded away.
Broken or Eroded Tie Rods

This is a wider shot of the same location showing the eroded tie rod and missing TSP.
Broken or Eroded Tie Rods

Case #1:

One plant found pieces of FM in the inlet pass of the highest pressure FWH and it was identified as the SS tube covering of the tie rods in the nest lower pressure heater. They were eroded by steam flow and went out through the drain and then went through the HP pump and got chopped up into smaller pieces. The pieces large enough to not go into the tubes were removed from the channel head. Then ALL tubes were then shot with felt plugs with water and air from the upper (outlet) pass to ensure there was nothing left in the tubes. This reverse flush is important because if they stopped at the U-Bend it would be easier to move them from the opposite direction.

The FWH’s were replaced for power uprates within a couple outages and no tube damage was identified up to that point.
Broken or Eroded Tie Rods

Case #2:

The plant found pieces of FM in the screen basket on the FWH drain tank that lead from the second highest pressure FWH. The pieces were fairly large and were easily identified as the SS tube covering of the tie rods in the FWH. They were eroded by steam flow and went out through the drain and were caught in the basket.

This FWH was also previously included in the discussion of TSP erosion. Before FWH replacement was to be scheduled this unit has been retired for other reasons.
Stress Corrosion Cracking at Tubesheet Crevice / Roll

While this has been identified in the past the chemistry has stabilized in the industry and the tubesheets can be expanded to eliminate the crevices.

There needs to be three conditions present to have SCC in T-304 SS:

1. High residual stresses like at the roll transition.
2. A concentration of Stainless Steel susceptible corrodant like chloride within the tubesheet crevice.
3. Temperatures that exceed 150°F.
Leaking / Ejecting Plugs and stabilizing Cable

It has been identified that when tubes are plugged they can become pressurized during operation. It is believed any moisture remaining in the tube heats up and expands. If the plug is not seated very securely and is disrupted it can become a projectile as pressure ejects it from the tube.

There have also been instances where the lubricant on the wire rope stabilizer cable broke down during operation temperature and ignited during the ejection/decompression process and created a fireball.

It has been reported if there is no actual tube leak prior to plugging that some plants now puncture the tube to allow the pressure to neutralize.
Review of Design Drawings

Whenever possible the design / ‘as built’ drawings should be reviewed prior to ECT inspections. Important information can be identified like shell penetrations and/or damage prone areas that should be included in the inspection scope. Also other information that can be found on the HX specification sheet like tube material, diameter, wall thickness (BWG), length(s), tubesheet/tube support materials and thicknesses, operating temperatures and pressures, shell & tube side medians. All these items can become very useful in identifying damage mechanisms and possible corrective actions. This can also help determine if modification of the inspection approach or technique needs to be incorporated to identify potential damage mechanisms.

Also actual design or manufacturing errors can be identified if the ET results show conditions (# of or spacing of TSP’s, tube lengths…) that do not match what the drawings / specification sheet document.
Modifying ET Techniques

In some instances the inspection technique should be modified to ensure the damage mechanisms of concern can be identified during the analysis process. This can include, but is not limited to; inspection frequency(s) (kHz), screen sensitivity (higher or lower), probe type (U-bend, array, MRPC, magnetic saturation). In one instance to help identify a potential problem a duplicate process channel(s) can be used at a very high or low screen span to ensure it be seen. In another instance if unexpected indications are found then a magnetic saturation probe should be used to discount permeability variations.

An open mind and flexibility in approach are very important to ensure tube integrity because if you aren’t looking in the right direction you won’t see it.
As Found Inspection

Performing an ‘as found inspection’ is very important. In the case illustrated below, the craft opened a FWH and then contacted engineering that it was opened but that they found items in the channel head. Upon ‘as found inspection’ it was determined the items were the partition plate retaining nuts and washers. The utility had taken precautions to prevent this but the tie wire had failed. A number of the nuts and washers became FM in the inlet pass channel head. Over time they peened the tube end seal welds so much that inspection of a very large number of tubes was not possible. This was because the diameter of the inspection probe would need to be so small to pass it would not meet industry recommendations or give meaningful results.

This condition was documented and corrective actions were taken to prevent this from reoccurring.
As Found Inspection

Partition Plate Nuts & Washers
As Found Inspection

Partition Plate Nuts & Washers
As Found Inspection

Partition Plate Nuts & Washers
As Found Inspection

Peened Seal Welds Restricting ET Probe Passage
As Found Inspection

Peened seal welds restricting ECT probe identified in RED.
For More Information

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