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Tube Sleeves Breath Life into Failing HP Feedwater Heaters

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Abstract
Two HP feedwater heaters with heavy wall 304N stainless steel tubes that were eddy current tested and found with over 50 per cent of the tubes having 60% wall loss or greater from stress cracks. The heaters were critical to AEP's Tanners Creek 500 MW Unit 4's operation as they were in separate heater strings of two heaters each. Isolating the heaters would have required. A 50-75 MW curtailment of the 500 MW Unit.

This paper discusses how these two HP feedwater heaters were kept in service and are running reliably at design for the past 6 months with the large number of tubes having serious stress cracking. The 500 MW unit could not start up without at least one of the heaters and the plant would have to run at a reduced load if it were to be put on line without the heaters in operation. After performing eddy current testing, a tube sample was cut, pulled and inspected to verify the eddy current test results. Metallurgical analysis of the sample confirmed the stress cracking to be from thermal fatigue. Nearly all the defects were in the de-superheating zone between the back face of the tube sheet and six feet (6') from the tube sheet. Because of the possibility of catastrophic tube failure and potential for a Turbine Water Induction Event, the heaters would have to be taken out of service as there was no time for retubing or purchasing new heaters. Although sleeving HP supercritical feedwater heaters had not been done in the past, this seamed to be a possible alternative to safely keep the heaters in service.

The #7 HP Heaters were installed in 1994. No problems had been encountered with the heaters (i.e. no tube leaks) until the spring of 2009 when multiple tube failures occurred on both #7E & #7W HP Heaters. Due to the sudden increase in tube leaks, the decision was made to eddy current 100% of the tubes in each of the heaters during the planned Fall '2009 outage. The test results were shocking. A large number of tube contained sever stress cracks with most of the damage in the de-superheating zone.

Figure 1 AEP's Tanners Creek Station Lawrenceburg, Indiana

Figure 2 Supercritical HP Feedwater Heater 7W Hemi-head with 14"X18" Man Way

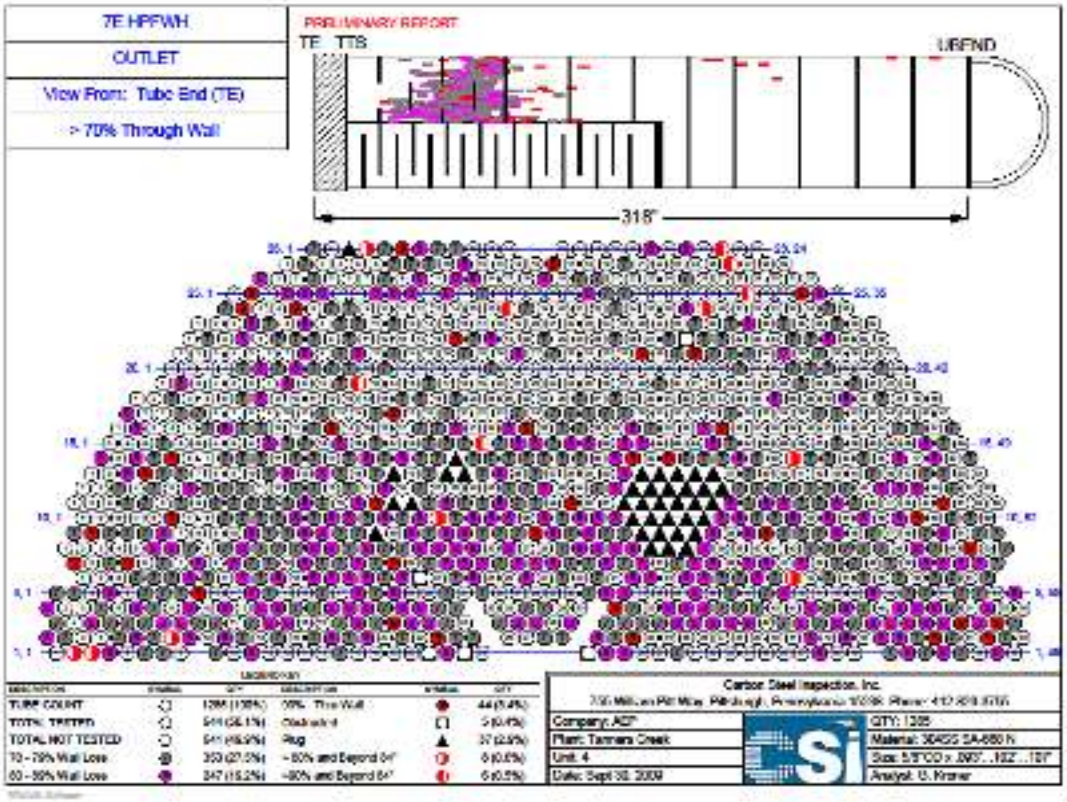

Figure 3. 7E Heater Eddy Current Results showing over 320 tubes with stress cracks over 70% of the tube wall most were in the de-superheating zone within 6 feet from the tubesheet.

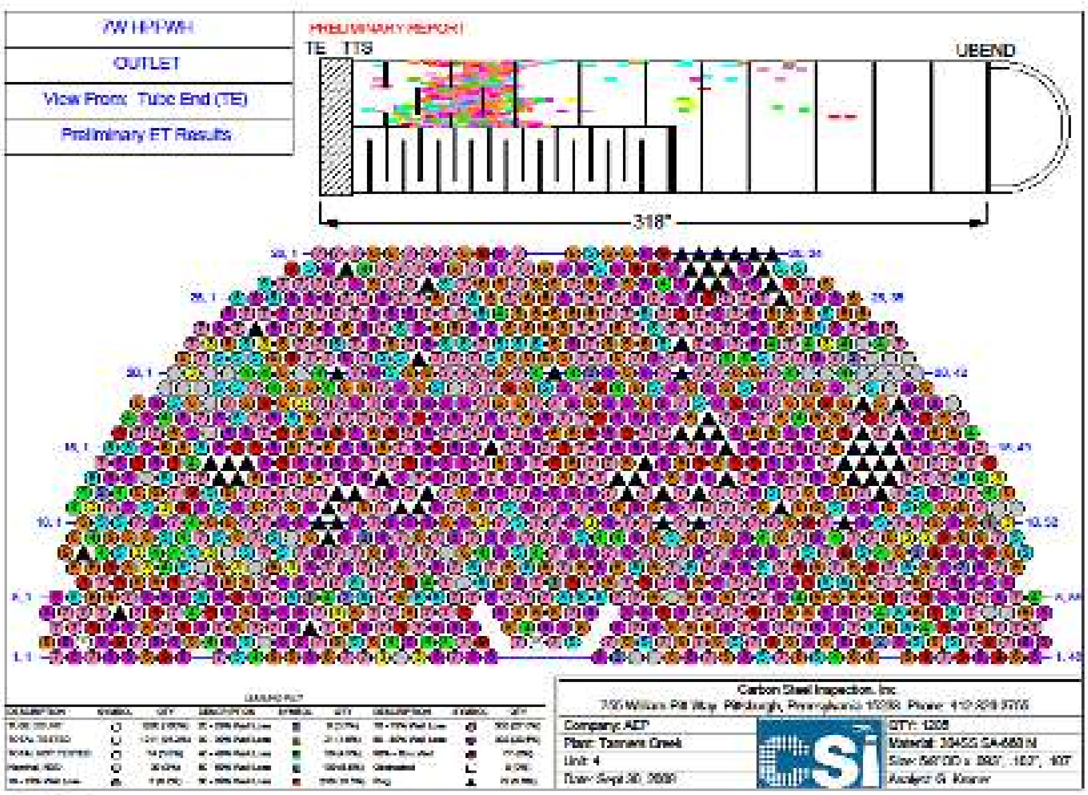

Figure 4. 7W Heater Eddy Current Results showing over 380 tubes with stress cracks over 70% of the tube wall, most were in the de-superheating zone within 6 feet from the tubesheet.

There were a number of difficulties to overcome. The heaters had small hemi-head channels which made it difficult to install seven (7') foot long 304 stainless steel sleeves. The room in the hemi-head was 8 to 30" deep X 54" high at the tubesheet with the pass partition plate removed.

The parent tubes were 5/8" OD with three different heavy wall thicknesses (.108, 102 and 098" wall). The parent tubes had .409, .421 and .429" ID's. Also there were only 20 days in the scheduled unit outage to complete the project from the day it was decided to go ahead with purchasing the sleeve material, vacuum anneal the sleeves, install (613) 7' long sleeves while working around a planned 3 day unit hydro (17 work days to complete the sleeving work).

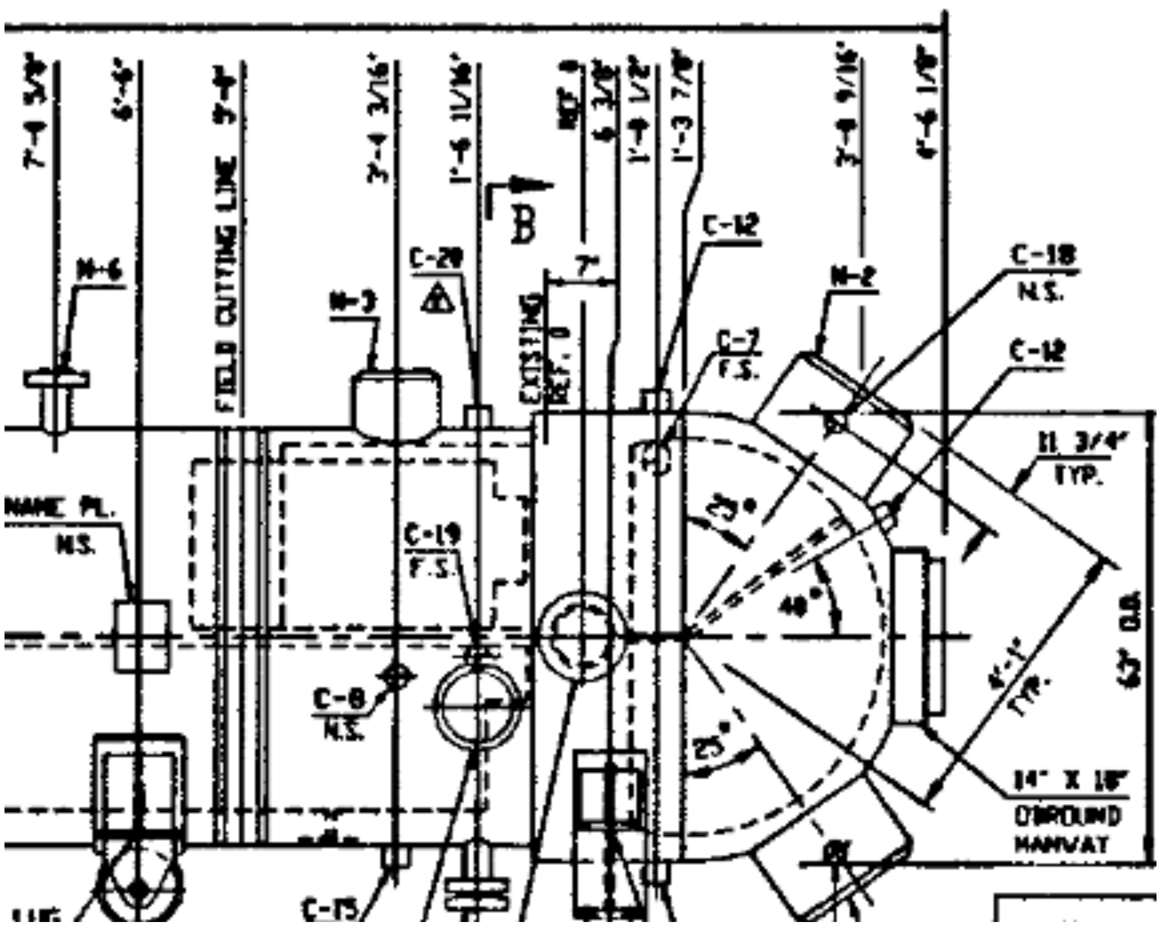

Figure 5. Hemi-head with 14"X18" man way and a 8 to 30" deep X 54" high work space to install (613) 7'long SS tube sleeves.

A plan to secure two different OD sizes of sleeves, to secure specialized hydraulic tube expansion equipment and to TIG weld the sleeves to the inside of the existing tube to tube sheet joint TIG weld was developed.

The sleeves were to reinforce the parent tubes and provide a leak free seal in the area of the parent tube that had the stress cracking (6' from the back face of the tube sheet in the de-superheating zone). It was also expected that no significant reduction in thermal performance of the heater would take place.

The heaters did not have to be abandon and the sleeve performance has been good so far through two short outages with no tube leaks and with no noticeable drop in thermal performance. The HP Heater on Tanners Creek Unit 4 have acoustic monitoring that is sensitive to very small tube leaks in these heaters. To date (over six months of operation) no tube leaks have occurred. This paper discusses the thermal fatigue tube cracking, the plan to install sleeves and the performance of the heater for the past six months. We believe this is the first time that long tube sleeves have been successfully installed in a supercritical high pressure feedwater heater(s).

<u>Tube Samples for Visual and Metallurgical Analysis:</u>

Figure 6. 5/8" OD X .108"W Tube Crack

Figure 7. Tube sample cut with patented Plasma Arc Tube Cutter "PATC".

Three pieces of HP heater tubing from the 7E heater de-superheating zone were sent to AEP's laboratory for metallurgical failure analysis. The pieces analyzed were all part of the same section of tube which was reported as not containing an actual failure but did have eddy current indications of 0.080" wall loss or greater. The three pieces were 21", 9 ½" and 4" in lengths. Examined under the stereomicroscope and used visible dye penetrant to identify surface-breaking defects in the tube. The photographs attached below show the visible dye penetrant indications. The indications detected were uniformly circumferential cracks.

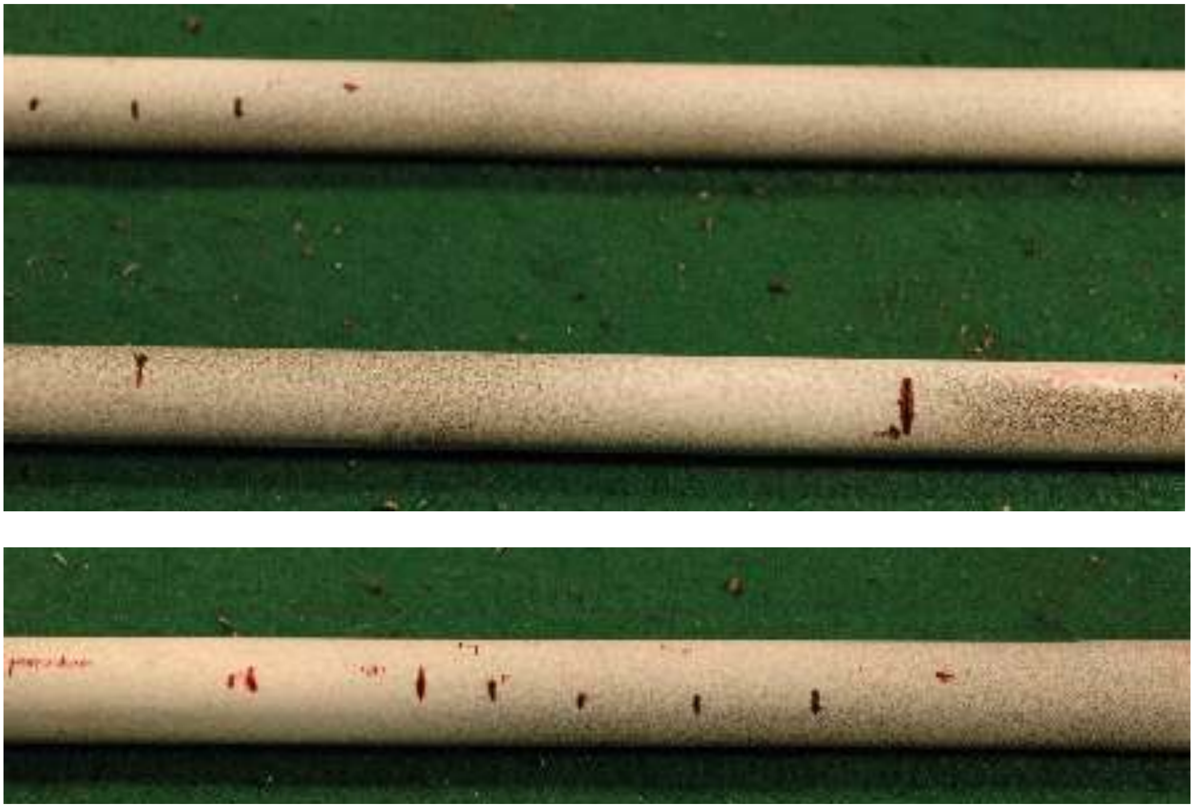

Figure 8. Dye penetrant indications in tube samples.

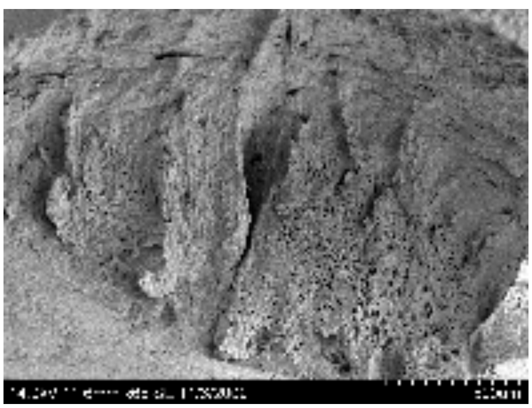

Figure 9. Thumbnail-shaped surface crack.

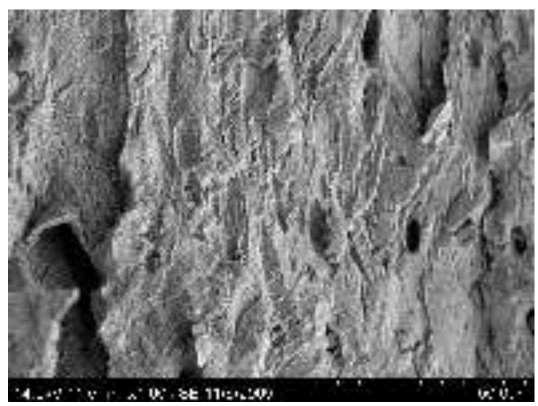

Figure 10. Transgranular crack texture with some brinneling damage present.

Several metallographic sections were prepared, polished on longitudinal faces normal to the circumferential crack pattern. Examination of these metallographic specimens confirmed that the cracks were blunt-tipped, transgranular with very little crack branching. This type of crack morphology and the number of cracks present suggests thermal fatigue cracking as a likely cause of the cracks.

Figure 11. Crossection of circumferential crack, transgranular, non-branched and blunt-tipped. 400X Oxalic acid etch.

<u>Metallurgical Summary as Reported by AEP's Metallurgist:</u>

Based on the evidence in these samples, the cracking present appears to be the result of thermal fatigue initiating circumferentially possibly in response to bending stresses present in the installation in the heater. The residual hoop stress, when added to the service stresses should be sufficient to cause longitudinal failures from stress corrosion cracking. Since this does not seem to be the cause of failure in this sample, it would appear that (1) sufficient tensile stress is not present to cause longitudinal stress corrosion crack failures, (2) there was insufficient corrodent present to promote longitudinal stress corrosion crack failures or (3) there was an unknown cyclic loading present that caused the longitudinal stress in the tube to become the principle stress relative to this failure mechanism.

<u>Alternative Solutions to bring the unit on line within the remaining 20 days of the outage:</u>

1. Purchase replacement heaters…………………..Lead time is over 12 months.

2. Rebuild the heaters in place……………………Tube material lead time is 12 weeks.

3. Bypass both heater strings…………………….Unit can not start up

4. Plug all the tubes with 70%+ wall loss defects..Heater would be 35 to 40% plugged.

5. Install sleeve/liners in the ID of tubes…………Keeps all damaged tubes open and to allow the best performance possible.
   with a 70%+ wall loss defects within the tubes in the de-superheating zones. Explosive plug tubes with large defects outside the zone.

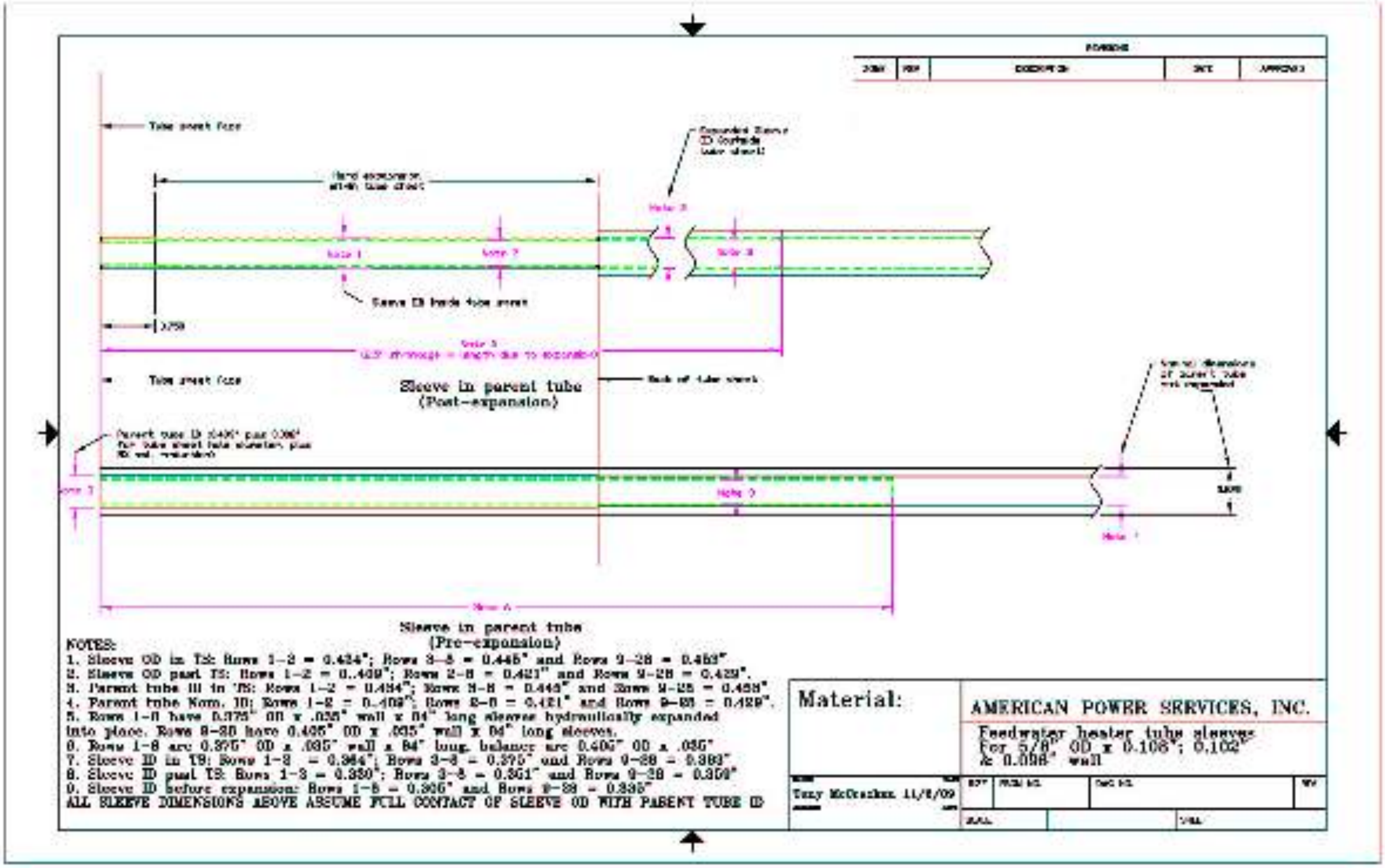

Figure 12. Sleeving three different parent tube sizes with two different sizes of tube sleeves.

Scope of Work:

Installation plan for pulling tube sample and installing 7' long sleeves/tube liners:

1. Cut and pull a tube sample to verify the Eddy Current Test results, for visual inspection and metallurgical analysis using the Plasma ID Tube Cutter.

2. Visually inspect heavy wall tube sample and perform metallurgical analysis.

3. Remove the pass partition plates to within 2 inches of the tube sheet and channel.

Scope of Work continued:

4. Clean tubes with felt plugs through every tube in the heater to remove any excess water that may have been inside the tubes that would have been drawn out during TIG welding the sleeve to the existing tube joint weld.

5. Wire brushed the tubesheet face and existing TIG tube joint weld to remove red-oxide, dirt and grease that may be present so as to not contaminate the TIG welds.

6. Burred the first inch of the tubes needing sleeves in the first 8 rows.

7. Installed the sleeves in the first 8 rows (a total of 381 sleeves were installed in both heaters: 7E-265, 7W-116).

8. The first 381 sleeves were welded to the existing tube joint weld. The welds were inspected and repaired as needed.

9. The 7' long sleeves were then hydraulically expanded the full 7' length.

10. The fronts of the sleeves were then roller expanded to the tube ¼" behind the sleeve to TIG weld.

11. The heaters were closed for 3 days for a scheduled boiler hydro.

12. Drain and open heaters. Shot felt plugs through the remaining rows of tubes needing sleeves to remove dirt and water.

13. Installed sleeves in the remaining parent tubes that had 70% wall loss or greater (total of 613 sleeves were installed in both heaters: 7E-359, 7W-264).

14. Welded remaining sleeves to the tube joint welds. Welds were inspected and repaired as needed.

15. After all the sleeves were installed and TIG welded, the sleeves were hydraulically expanded. The expansion was done after all welding because the lubricant that was used to make the installation of the expansion mandrel into the tubes would contaminate the new TIG weld. For this reason the installation and welding of all the sleeves were performed before any expansion.

16. The fronts of each of the sleeves were mechanically expanded at ¼" behind the sleeve to tube joint weld.

17. A shell side hydro test was then performed.

Figure 13. 0.405" OD X .035 wall X 7' long 304 stainless steel, vacuum soft annealed tube sleeves.

Figure 14. Hydraulic Expansion Mandrels designed to fit into the 7E and 7W heaters confined space.

Figure15. Hydraulic Expansion Gun used to expand show the quality of the weld.

Figure 36. Partially TIG welded the sleeve to the 7' long sleeves into the parent stainless steel tubes.

Summary of the heaters performance since sleeved.

After the sleeving project at Tanner's Creek was finished, Jay King, Plant Engineer, was surprised to see the heater performance was substantially maintained.
"We would have expected to see a slight performance decay, since you have the sleeves in place in the de-superheating zone," he says. "Because it's now a heavier-walled tube. But that didn't happen. We maintained the same performance levels. The TTD (terminal temperature difference) and the saturation temperature of the heater (based on the pressure) versus the feedwater outlet, have not decayed at all." Quite possibly that resulted from the selective, limited use of sleeving.
"The thing I liked best about going this route is that we didn't have to abandon the heaters," "That would have presented us with a very difficult situation on how we would start and shut down the unit without some serious pipe modifications and major changes in operating procedures. These heaters are used during start-up and are equipped with alternate drains that drain back to the condenser that must be utilized during start-up. The piping modifications would have meant a large added O&M expense and time lost for engineering to assess needed operational changes. The installation of the sleeves allowed us to maintain efficiency and return the unit to service maintaining a design base".

Key Sleeving Results of AEP Tanners Creek Sleeving Project:

- Didn't have to abandon the heaters
- Significant amount of pipe modifications for bypassing the heaters and for start and shut down of the unit were not necessary.
- Returned the unit to service within original outage schedule (20 days from decision to sleeve)
- The heaters have not been opened since the sleeving project in Nov 2009
- The 7E and 7W heaters have sonic leak detection equipment to monitor very small tube leaks. No indications since Nov. 2009
- Maintained the same performance levels
- TTD & DCA have not decayed at all
- Delayed the need for Capital Purchases for Rebuilding On-site or for Fabrication and Installation of New Heaters

July 2010: Tube Sleeves have proven to restore life in feedwater heaters and other tubular heat exchangers. The following is the current state of the art:

1. Supercritical high pressure feedwater heaters can be sleeved to extend heater's life.

2. Sleeves can be installed in heaters with small hemi-head channels with small man ways.

3. HP, IP and LP FWH's with sever tube defects have been kept in service by installing tube sleeves.

4. Sleeves can patch tube defects by forming a leak free seal on both ends of the sleeve within the parent tube anywhere along the length of the tube by brazing the sleeve to the existing parent tubes.

5. Sleeves covering through wall holes have been hydro tested to 5,000 psi with no tube leak.

6. Eddy Current Testing can identify all tube defects along the length of the tube. These defects can be patched with one or multiple tube sleeves any where along the straight length of the tube.

7. Plugs can be removed and the tubes can be restored to service resulting in improved reliability and thermal performance.

8. The life of feedwater heaters, condensers, and other tubular heat exchangers can extended with leak free tube sleeves.

9. Capital purchases for rebuilding or replacing existing feedwater heaters and condensers can be reliably delayed for years by patching tube defects and tube leaks.

10. Tube inserts have proven to stop inlet erosion in heater and condensers with admiralty brass or carbon steel tube material to stop inlet erosion.

11. Full length tube liners (sleeves) can be installed in tubes with damage along the full length of the tubes keeping the tubes in service.

12. Explosively welded tube sleeves can replace leaking tube to tube sheet TIG welds (cracks, pin holes, porosity) and form a leak free seal. Sleeves are welded to the tube sheet hole and to the existing tube within the tube sheet.

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