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EPRI Case History Study: High Pressure Feedwater Heater Replacement

A Success Story in Outage Management and Project Execution

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EPRI Project Manager

R. Chambers

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1395 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

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Principal Investigator
F. Causey

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ABSTRACT

U.S. utilities are faced with the need for continuous change in the way plants are operated and maintained. A focus on generation costs sets the stage for innovation in the way fossil plant outages are planned and managed. While nuclear plants have been pioneers in this area, fossil plant managers and support staff are now recognizing ways to extend runs between outages and minimize outage duration. This is being accomplished with aggressive application of condition-based maintenance, and improved outage management, including tighter controls and better planning/engineering of plant modifications and upgrades.

This case study takes a high-level look at one plant upgrade performed at a major southeastern U.S. utility in the context of how it contributed to a successful unit outage. The perspective will be that of the engineering firm authoring this case study, who also provided the engineering package for this plant upgrade.

Engineering outage challenges focused primarily on crane upgrades and structural modifications required by increased feedwater heater loads.

The upgraded feedwater heaters were successfully installed on schedule, and within 2% of the final cost estimate. Contributing to this level of accuracy were factors such as the level of design completion, level of accuracy in bills of materials, experienced project and outage management, and the use of experienced subcontractors.

Also examined are lessons learned from this project that will apply to similar upgrades throughout the industry.

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1 INTRODUCTION

A major southeastern utility successfully completed a high-pressure feedwater heater replacement, one of several significant tasks performed during the Spring 2003 outage. The owner utilizes a proprietary Outage Management Process Manual to control outage planning and execution. This process manual is extensive and comprehensive in it's definitions of key roles, responsibilities, and processes used for complete outage planning and management.

Outage planning is executed in six phases:

1. Conceptual - Planning that occurs 30 to 18 months prior to the outage.
2. Preliminary - Refinement of the conceptual plan, occurring 18 to 12 months prior to the outage, and adding details to projects, work lists, etc.
3. Detailed - Completed six months prior to the outage, finished activities would include awarding of project contracts with vendors.
4. Pre-Outage Work - This includes completion of materials requisitions, outage schedules, safety and contingency plans, and other detailed components of the overall execution plan.
5. Outage Execution - Actual execution of the work, accompanied by progress reporting to management, along with preparing to return the unit to service.
6. Post-Outage - Normally extending up to 4 months after completion of the outage, activities remaining would include final payment of invoices, final reporting to management, and the completion of as-built drawings.

The various tasks and functions described in the feedwater heater replacement outage align with multiple phases of the outage plan provided above. For example, Scope Definition is included in the first three phases referenced above.

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SCOPE DEFINITION

Project scope covers the replacement of two high-pressure feedwater heaters. The new heaters have stainless steel tubes and a hemi-head design resulting in increased length, diameter, and weight, as well as some new nozzle locations. Modifications to the turbine building were required to set the heaters and handle the additional weight. Included in the work scope was the design for the removal and disposal of the old heaters (shown below in Figure 1), installation and reconnection of the new heaters (shown in Figure 2), replacement of small isolation and relief valves, review of heater instrumentation and level controls, review and potential redesign of floor openings and structural steel, and review and potential redesign of the heater drain and vent systems. A modification to the turbine-building crane was required as well.

The lifting and rigging plan for this job included a crane modification designed by the OEM to allow for a one-time engineered lift of 259,000 pounds plus rigging.

Figure 1
Old Feedwater Heater Ready for Disposal

Figure 2
New Feedwater Heater Prior to Uprighting Over Heater Bay

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RESPONSIBILITY MATRIX

For this project, the owner handled procurement and construction activities and the engineer was responsible only for the engineering package. Specific deliverables for all parties were identified in the project scope document, and are listed below.

Engineer

Civil

1. Provide a lifting and rigging plan for removal of the old heaters, and the unloading, moving, and installation of the new heaters.
2. Review floor openings for clearances needed to lower new heaters into place. Provide design for floor modifications/core drills as needed. Include floor support steel as needed.
3. Determine if the new heaters should be shipped with or without heater support brackets.
4. Redesign the checkered plate support steel for the new heaters.
5. Redesign the lateral bracing structural attachments for the new heaters.
6. Review existing heater support stands for the weight and height of the new heaters and provide the design for any modifications needed.
7. Provide stress analysis and support/restraint design for all new or redesigned piping.
8. Provide guidance on receiving and storing new heaters.
9. Review existing crane(s), lifting beams, etc. and coordinate with crane supplier to provide any designs needed to support lifting and rigging plan.
10. Review any crane modification designs provided as part of this modification.
11. Issue bills of materials to allow the station to requisition support/restraint materials and miscellaneous steel.
12. Provide as-built drawings.
13. Evaluate other structural members potentially impacted by heater replacement (column E31) and provide the design for any modifications required.
14. Provide railcar loading instructions for transporting the heater to the station.
15. Provide the design and bills of materials needed for any cold-pull restraints.
16. Provide on-site engineering support during the crane modification.

Mechanical

1. Provide new or revised P&Ids for feedwater, heater bleeds and drains, heater vents, heater relief valves, and heater level controls. Also provide as-built P&Ids.
2. Review and transmit heater vendor drawings.
3. Provide preliminary, final, and as-built piping drawings.
4. Provide data sheets for the shell-side and tube-side relief valves and flex-hose.
5. Provide data sheets for all necessary isolation valves.
6. Review feedwater system design conditions, pipe spec. requirements, etc.
7. Provide insulation requirements for new installation.
8. Provide engineering instructions.
9. Provide vent system orifices (coordinate with mfg.)
10. Provide Project Manager.
11. Provide on-site support during heater installation.

Electrical – I&C

1. Review heater instrumentation and drains control design.
2. Provide any new I/C design required because of new heater design.
3. Provide any bills of materials needed to requisition I/C components needed to support this design. The station will issue actual requisitions.
4. Provide electrical engineering support for turbine building crane trolley change out.

Installation Contractor

1. Fabricate and test lifting beam if necessary.
2. Remove existing heaters.
3. Install new heaters.
4. Install new piping and valves associated with the new heater design.
5. Insulate the new heaters, piping, and valves.

6. Provide for the inspection, and repair (if necessary) of the rail spur to be used for bringing the new heaters into the turbine building.
7. Install structural steel modifications needed for increased heater loads.
8. Install structural steel modifications needed under area used for uprighting the new heaters.
9. Support engineer in development of the lifting and rigging plan.
10. Issue material requisitions from bills of materials supplied by engineer.

Owner

1. Provide vendor surveillance during heater manufacturer.
2. Conduct heater performance testing after installation at the station's request.
3. Provide project funding.
4. Provide Contract Administrator.
5. Provide funding for OEM crane evaluation and modification.

Plant

1. Install instrumentation associated with new feedwater heaters.

Project Management

1. Arrange for disposal of the old feedwater heaters.

4
COST ESTIMATING

The costs of the crane modification engineering, materials and installation were not included in the engineering scope or cost estimate of the feedwater heater replacement, but were separate items.

Engineering and materials were provided by the OEM and the installation contractor was selected by the owner.

Within this utility capital project funding is done in two phases. Phase I is initial funding based on a cost estimate compiled using a project scope document, prior to design completion, and using a rough estimate for craft labor and materials cost. This level of estimating is ideally completed in the conceptual phase of outage planning, with an expected accuracy of +/- 20%.

Phase II funding is based on a complete design, allowing for accurate installation and materials cost estimates. The detailed outage planning period is the appropriate time for Phase II cost estimating. Accuracy of the Phase II estimate, with the design information normally available at this time, is +/- 5%.

For this project, the final project cost was within 2% of the Phase II estimate. Factors contributing to the accuracy are:

- Level of design completion at time of estimate
- Level of accuracy in bills of materials
- Experienced Project/Outage Management
- Use of Experienced Sub-Contractors (Engineering, Installation, Crane Upgrade)

5
ENGINEERING PHASE

The utility provided the specification, including performance criteria, for the new heaters. Therefore the engineering phase began with a set of relatively complete vendor drawings showing new dimensions, weights, and nozzle locations.

One of the major challenges was the increased size and weight. The owner's specification provided improvements in performance, reliability, and component life. However, this resulted in a replacement heater considerably longer, wider, and heavier than the original. Floor steel reinforcement, and modifications around the heater bay openings were relatively easy to provide. However, development of the lifting and rigging plan proved to be an interesting exercise.

The turbine building crane is a two-trolley design with an overall bridge capacity of 200 tons. However, each of the two main trolleys was rated for 100 tons only. There was a third auxiliary hook as well rated for 20 tons. The new heater had a design weight of 259,000 pounds (130 tons) empty, so either an upgrade to the bridge crane, or utilization of a mobile crane was going to be needed for the lift.

After considering several options utilizing mobile cranes, it was decided to upgrade the turbine building crane to provide the station with main trolleys rated for 150 tons, while the bridge remained rated for 200 tons. This allowed the development of a lifting plan, utilizing only the permanent turbine building crane, to move the new heaters from the railcar into their permanent installation. New heaters are designed with upper and lower trunnions allowing for utilization of both of the 150-ton trolleys. Slings are looped around the trunnions and threaded through the main hooks of both trolleys to distribute the massive weight.

These feedwater heaters are U-tube design with channel inlet and outlet connections on the lower head. The original heaters were full-access channels with bolted covers providing channel inlet and outlet nozzles perpendicular to the heater. Replacement heaters are a hemi-head design where the feedwater inlet and outlet nozzles were 30 degrees below perpendicular. The impact this had on feedwater system connections was the most significant piping design issue. Rerouting feedwater inlet and outlet lines to the new nozzle locations was accomplished with surprisingly little impact in the already crowded area between the mezzanine and turbine room floors.

Being just downstream of the feedwater pumps, feedwater lines connecting the high pressure heaters have some of the most extreme design conditions in the plant, requiring pipe wall thickness over two inches. The high thermal stresses involved require pre-stressing using temporary "cold-pulled restraints" installed before the cuts were made to the feedwater line. Once new piping was in place, the temporary restraints were removed, and permanent supports and restraints carried the operating loads.

Structurally, high loads from new heavier heaters had to be considered all the way from the rail spur entering the turbine building to the support steel around and under the heaters. The initial idea of reinforcing existing steel underneath the heaters was scrapped in favor of adding new columns transferring the additional load down to the basement floor. This represented a savings in both schedule and construction scope.

Figure 3 shows support leg extensions needed for the new feedwater heaters.

Figure 3
New Feedwater Heater Showing Support Leg Extensions

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MATERIALS ISSUES

With piping design completion only weeks before the outage, materials had to be fast-tracked. In addition, a new materials requisitioning system was in place at the utility. The result was acceptance of heavy-wall pipe with excess wall thickness (up to ¾” beyond minimum wall). The additional machining required in the field for weld-preps for proper match-ups proved to be expensive and time-consuming (see the 16-inch elbow in Figure 4). A key point in the lessons-learned summary was to provide piping bills of materials far in advance of the outage on the next project.

Careful procedures for hazardous materials abatement and removal were built into the outage plan as well.

Figure 4
16-Inch Elbow for New Feedwater Line

7 PRE-OUTAGE PLANNING

Project schedule development involved the integration of three separate schedules: engineering, procurement/manufacturing, and implementation. The engineering schedule was abbreviated and focused on milestones needed to support the overall project, such as design release dates. The owner was responsible for procurement and installation, and therefore maintained the overall project schedule and used input from engineering to develop and maintain the overall integrated schedule.

The pre-outage work consisted of two work scopes related to this modification.

The first was adding new columns to the floor support steel below the heaters, between the mezzanine and basement floors. Figure 5 depicts these new supports. This work was handled pre-outage but still required careful planning because of the nearby 4160 volt bus duct shown to the upper left of the columns to the left of the light fixtures. Steel modification work was done in the fall of 2002.

The second was the turbine building crane modification. This was outsourced separately to the crane OEM and had to be complete prior to the start of the outage. During this same outage there were other major projects, such as turbine maintenance, requiring use of the crane, so accurate, on-schedule completion of the crane work was critical to the success of the outage. The crane modification work was done in late winter, prior to the spring 2003 heater replacement.

Figure 5
New Support Columns

8
CONSTRUCTION ISSUES

There are 40 connections on each heater, most of which are between the mezzanine floor and turbine room floor. Although several of these are maintenance drains that aren't connected to piping, the nozzles that are connected to permanent piping systems provide a view looking up from the mezzanine floor that can best be described as "spaghetti." Obviously this presents some installation issues for the pipe fitters. Pipe work including cutting, welding, NDE, hanger installation, and thermal insulation all had to be carefully coordinated. For these heaters, the largest line was 16" (feedwater) with a minimum wall thickness of 2.19 inches. All piping was carbon steel.

Figure 6 shows the installation work under way on the new feedwater line.

Figure 6
Feedwater Line Welding

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OUTAGE ACTIVITIES COORDINATION

This station, like many, has permanent planners on staff who provide a detailed schedule of all outage activities. Individual project schedules are integrated into the master schedule by the planner. It is his responsibility to coordinate concerns such as crane availability, craft utilization, staffing, station access, rail spur access, laydown space, staging areas, and other factors that contribute to a smooth outage.

During the outage, regular meetings with craft, contractors, safety, engineering support and project management help to identify issues before they escalate into problems. Decisions to double-shift or add labor are made as the outage progresses.

Weld preparation or repair work is shown in Figure 7.

Figure 7
Sparks Fly During Weld Prep/Repair

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INSTALLATION ISSUES

Lifting the new longer, wider, and heavier heaters was the dominant installation concern, requiring a detailed lifting and rigging plan. Although the heaters were set on “feet” having the same footprint as the old heater, the larger shell diameter required that one of the three legs be shipped loose, and welded on in the field. The new heater had to stay on the crane hook until the third leg was welded on.

Kevlar slings were used around the trunnions to rig the heater to the crane. While the heater was vertical, supported only by the upper trunnions, a tear developed in the protective sleeve surrounding the sling. Although the structural integrity of the sling was intact, the visibility of the tear provided some anxiety for the rigging crew and crane operator. Figure 8 shows the feedwater heater being uprighted in the turbine building.

Turnover activities were coordinated by the station responsible engineer, as was startup testing. The installation contractor provided red-marked as-built drawings to the engineer for revision and transmittal.

Figure 8
Uprighting Process

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LESSONS LEARNED/BEST PRACTICES

After job completion, a meeting was held with engineering, the utility, and the installation contractor to discuss the significant conclusions that could be taken from this job and applied to future work. These are summarized below.

1. Inspection of the crane rail extensions needs to be an early activity. If they appear to be in good condition, further review of their design may be added to the scope.
2. Final design completion needs to be well in advance of construction start. This would include the lifting and rigging plan. Engineering target is hitting 100% of scheduled engineering release dates.
3. Structural design needs to be complete in support of the spring 2004 outage. The current scheduled completion date for this is 11/15/03. (Note: this was about 5 months in advance of the outage).
4. Tighten up requirements and delivery of heavy wall pipe and fittings. Need to minimize excess wall thickness which leads to expensive weld prep. This will require an early release for piping bills of materials. Have materials on site in time to allow for pre-outage prep work.
5. Need to build in a review cycle through owner's engineering for contractor-issued engineering documents.
6. Need to include some spares or excess materials on the piping bills of materials so that the station has everything needed on-site.
7. Basement support columns are preferred.
8. Consider the following changes to the unit 4 heaters:
    - Extend length of upper trunnions two inches to accommodate wide chokers.
    - Have every leg at least tack-welded on.
    - Change the "N" connection (shell-side relief valve) to 2" to match the existing valve.
    - Reexamine location of guide lugs connecting to horizontal stabilizers. Unit 3 worked well, but was a change from the original design.
    - Have the manufacturer stencil nozzle markers on at the factory.
    - Reconsider the need for capped nozzles (such as emergency drains). Make sure all nozzles that need to be capped are capped at the factory.

- Consider adding leg extensions to the manufacturer's scope.

9. Reexamine specifications for rigging slings in light of unit 3 experience. Why did the sleeves tear and what changes need to be made for the slings used on the next lift?

10. Have a civil and mechanical engineer on site for two weeks near the start of the outage.

11. Scope out electrical interferences more carefully for field-routed piping.

12. Reexamine leg base plate material, welding, and bolting requirements. Base plate bowed due to welding on one side only resulting in some bolts being too short.

13. Engineer needs to be copied on communications between heater manufacturer and the owner.

14. Engineer requests that the station verify the new crane hook elevations.

15. Verify that all materials are clearly called out on bills of materials.

16. Clarify the phase 2 estimate to identify materials to be purchased, but not yet identified on design drawings or bills of materials.

17. Identify thermowell locations more clearly on drawings.

18. Get early buy-in from all parties on lifting and rigging plan.

19. Note small lines, such as pressure equalization lines around valves, on design drawings, even if dimensions are unknown

20. Reexamine design of new lifting lugs for old heaters. Owner feels that unit 3 design was too conservative and could have been improved if shell thickness measurements of old heaters were used in the lug design

21. Reexamine cribbing design. Owner felt it was too conservative.

22. Issue hard copy drawings on the transmittals.

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