UTILITY BOILER CONDITION ASSESSMENT

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INTRODUCTION AND BACKGROUND

During the decade of the 1980's, life extension programs in many different forms, have been implemented and utilized by utility owners as a means of assessing the present physical condition of fossil fired boilers and their auxiliary equipment. The results from such programs have provided the owner with an estimate of the life expended to date of critical pressure components, together with a prioritized list of recommendations addressing near and long term maintenance, repair modification, replacement and monitoring items necessary for continued reliable operation of the unit in an extended time period. The owners intended future mode of operation has been factored into these assessments.

In the absence of any meaningful planned near term extensive building of new generating capacity, the Electric Utility Industry will have to continue to implement boiler and plant condition assessment projects as a means of at least maintaining present capacity in a marketplace of growing demand. The experience gained from the many successful ongoing and completed programs performed over the past eight years will be invaluable as we approach the decade of the 1990's. This experience is supplemented by the many advances made and developed during this period, especially in fiberoptic and video probe inspection equipment, on-line diagnostic monitoring systems, nondestructive testing methods and equipment, and computerized anaytical modeling techniques. Many of these inspection, montoring and analytical methods and tools have been developed as part of the many ongoing Electric Power Research Institute programs.

Although the term "Life Extension" has been receiving all the attention in the Utility Power Industry in recent years, Riley Stoker has been involved in the individual activities that make up a Life Extension Program for many years. In the late 1970's, Riley initiated a Boiler Availability Improvement (BAIP) Program. Riley has had a continuing Team Inspection Service (TIS) Program in place for the past twelve years, with over one hundred thirty (130) on-site detailed inspecions performed for both Riley and other manufacturer's boilers. In addition, Riley has extensive experience with in-house metallurgical analysis of boiler components, tubes, etc., with over twenty five hundred (2500) reports issued to date. Riley has performed many on-site boiler performance tests, and in-house engineering studies including remaining life estimations, for a revised mode of boiler operation.

The Riley Stoker boiler condition assessment program was formulated and introduced in 1985, and is described in Reference 1. This paper presents an update on the Riley program for boiler condition assessment, with special emphasis on typical pressure part failure or problem areas, and enhancements and upgrades relative to the mechanical design, materials and performance of boiler and fuel burning components.

CONDITION ASSESSMENT PROGRAM

The Riley boiler and equipment assessment program is comprised of the following key elements:

- Pre-Inspection Planning
- Review of Documentation
- Inspection
- Nondestructive Testing
- Destructive Testing & Metallurgy
- Performance Testing and Evaluation
- Expended Life Analysis
- Reporting

For a given project all, or a portion of these work tasks, are performed. For original Riley equipment, the OEM experience in boiler design, drawings, records and field service files is invaluable to a condition assessment program.

Pre-Inspection Planning

Pre-inspection planning is a most important feature for a successful condition assessment program. Part of the planning typically includes an on-site meeting, where all parties can review the preparation activities required for the inspection and testing work tasks. The preparation activities include, the opening of all boiler and equipment access doors, scaffolding, lighting, and power at the proper locations, access into headers and spray stations for internal inspection, preparation of tube and header surfaces for ultrasonic and replication testing, and removal and replacement of tube or core/boat samples for metallurgical evaluation.

Review of Documentation

During the inspection the Riley Team will review operational, maintenance, outage, failure analysis and previous testing documents and records as a means of establishing a history of the boiler. This review is supplemented by interviews with plant maintenance, operational and engineering personnel. This historical information is invaluable in identifying problem locations, and for providing inputs for the expended life calculations.

Inspection

A detailed visual inspection is performed for all regions of the boiler and fuel burning equipment. Measurements and photographs are taken as appropriate, and observations and findings recorded for such items as structural damage, interferences, misalignment, corrosion, erosion, pluggage, swelling, bowing and sagging of structures and components. The visual inspection includes boiler pressure parts, the setting, structure, air and flue gas systems and fuel systems. Outside diameter and circumferential measurements are taken at several locations along high temperature superheater and reheat outlet headers as a check on creep swelling.

Internal fiberoptic or video probe inspections are performed for the high temperature S.H./R.H. outlet headers, the lower hopper headers and the economizer inlet header, and superheater/reheat spray assemblies. These inspections are done as a check on internal deposits, corrosion and cracking.

At a spray station, the spray nozzle is dye checked for external cracking, and the spray liner, including seam weld, and attachment rings and welds are inspected for internal scale, deposits, pitting, cracking, corrosion and erosion.

The internal component inspections are recorded on video tape, which provides a permanent record for the client's and Riley's files. The state of the art in current available fiberoptic and video chip equipment has increased dramatically in recent years. This equipment includes scan-zoom borescopes, and flexible fiberoptic and video probes, up to 100 feet in length, with sophisticated monitoring and recording capabilities for freeze frame, image enhancement and measuring capabilities.

Nondestructive Testing

A variety of nondestructive testing tasks can be utilized as part of a comprehensive condition assessment program. They are summarized as follows:

Ultrasonics:

Ultrasonic testing is utilized for a variety of tasks. They include a boiler tube thickness survey, including the capability of measuring internal oxide scale. Ultrasonic shear wave techniques are utilized to locate and measure laminations in component walls, and for locating and measuring internally thinned tube regions caused by hydrogen embrittlement and caustic gouging. Finally, ultrasonic tip diffraction methods are used to locate and measure internal header, and external tube nipple cracking.

Magnetic Particle and Liquid Dye Penetrant Testing:

These nondestructive examination methods are utilized to determine the presence of any indications or cracking on the external surfaces of pressure components, and also internally, as accessible. Magnetic particle testing can be performed on a large number of components, such as tube to header and drum welds, in a relatively short amount of time. Dye penetrant testing is utilized in the less accessible regions, including welds, of a component.

Eddy Current Testing:

Eddy current testing is presently becoming a very viable nondestructive tool in a condition assessment program. Eddy current probes are being developed to identify and measure both external and internal pressure part surface and weld cracking. A very useful application of eddy current testing, is for measuring generating bank tube thicknesses, by utilizing a long probe inserted down the tubes from inside a steam drum.

Surface Replication:

Replication is a non-destructive metallographic technique, where an image of a component's external surface is taken in the field on a plastic film, for later laboratory examination of the microstructure. It is a widely used method of monitoring the external surface microstructure of a high temperature componet at high stress regions. The structure is examined for evidence of spheroidization, creep voids, void linkups and microcracks.

Typically, replication is performed on high temperature steam outlet headers and piping, at suspect locations, girth welds, elbows and outlet nozzle to header welds. Each replica covers a portion of the weld metal, the heat affected zone and the component's base metal.

Destructive Testing/Metallurgy

Destructive testing is accomplished by selective boiler tube sampling, and core or boat sample taken from regions of suspect headers, or drums. Riley will furnish a repair procedure for core and boat sample locations as part of a program.

The tube samples are analyzed in Riley's Metallurgical Laboratory. They are measured for evidence of thinning, swelling, overtemperature and material degradation in the form of graphitization or spheroidization. A chemical analysis is performed on severe internal or external scale and deposits, to determine the cause of erosion or corrosion. For water carrying tubes an Atwood-Hale (6) test is done as a check on cleanliness. The information from these tests and analysis is valuable in assessing the overall boiler operating practices and feedwater treatment.

Metallurgical investigation is performed on a core or boat sample, where the condition of the microstructure, can be determined through the depth of the sample. Also, if the sample contains an encapsulated crack, the cause of the failure can readily be determined. This form of metallurgical evaluation is advantageous when compared to the replication nondestructive technique, where only the components surface microstructure is available.

If deemed necessary, accelerated stress rupture tests can be performed on specimens machined from core and boat samples. The results from these tests provide current material property data, in the form of minimum time to rupture values, for a component's material that has been in service for a number of years. A methodology for this type of testing is presented in Reference 4.

Performance Testing and Evaluating

On-line boiler performance testing is offered as an option to a condition assessment program. For such a program, operational data is collected at several steady state loads, and during typical boiler startup, restart and cooldown transient events. Air and gas side, and water and steam side operating data is collected. The recorded values are compared with the original predicted values, and any past performance values, as a check on the current operational characteristics. The evaluation will include the generation of a computerized heat transfer model to simulate the various ramp rates, using the actual boiler performance as the existing base. Limitations or deficiencies are identified from computer modeling. These deficiencies may be addressed through redesign of circuitry, upgrade of material, changes in operating philosophy and external system additions, where possible. A predicted performance tabulation with curves is prepared which can reflect a revised unit operating philosophy. The results from on-line performance testing are invaluable as inputs to the expended life calculations.

Expended Life Analysis

Several thermal and stress analysis tasks are performed for selected boiler pressure components as inputs to the expended life calculations.

Thermal flexibility analysis are performed to provide loadings and motions for critical header, piping and tube components. The effects of differential thermal expansions are a significant contributor to many of the component and weld failures occurring in recent times, especially in a unit which has been utilized in a cycling or peaking mode of operation, or with frequent swings in load.

Simplified fatigue analyses are performed using the inputs from the appropriate thermal expansion cases, and pressure loadings, together with the thermal gradient and discontinuity stresses associated with significant temperature transients or excursions, such as a hot restart event. The linear cumulative damage method is utilized for the fatigue evaluations, where the alternating stress values from each of the significant load set pairs are input, and the actual cycles versus calculated allowed cycles ratioed and summed to provide a usage factor value for a given component. The cumulative usage factor values provide a percentage of the components life expended to date. Fatigue analysis is typically performed for components of an economizer inlet header, and a superheater/reheat spray liner.

Simplified creep calculations are performed for high temperature superheater and reheat headers and piping. The Larson-Miller parameter and the Life Fraction rule are used for the creep analyses. These methods utilize stress rupture values at temperature, in determining the creep life expended to date. The Life Fraction rule provides creep usage in the form of linear damage. Therefore, it is possible to sum the simplified results of both creep and fatigue for a given high temperature component.

A tube nipple to header junction can be exposed to the internal localized effects of creep-fatigue. The creep is the result of a local (tube) overtemperature condition, and the fatigue is based on a steady state temperature imbalance existing between the local hot tube and the lower bulk steam temperature in the header. This condition can lead to internal header bore hole and ligament cracking. A more sophisticated three dimensional inelastic finite element modeling is utilized to evaluate the effects of this creep fatigue phenomena. If internal cracking is present, and accurate crack width and depth values can be measured by ultrasonic tip diffraction or eddy current techniques, then meaningful fracture mechanics analysis can be performed to estimate the crack growth rates and the subsequent component remaining life.

Reporting

Reporting is an ongoing feature of a condition assessment program.

A pre-inspection plan is generated and issued prior to the start of the on-site activities.

Upon completion of the on-site inspection and testing work, a wind-up meeting is held to discuss the Riley observations and findings. A copy of the field notes is given to the client when the team leaves the site. This provides advance information about the condition of the boiler components.

A detailed final report and a copy of the fiberoptic inspection video tapes are prepared and issued to the client after the completion of the on-site work activities. The report documents the results of the inspection, non-destructive testing, replication and analytical tasks described herein. It includes a summary and description of the inspection and assessment findings and conclusions for the subject critical boiler components. Based on the findings, detailed recommendations are presented which address near and long term maintenance, repair, modification, replacement and monitoring items in order of priority.

PRESSURE PART FAILURE INVESTIGATIONS

Over the past decade Riley has investigated many typical and unusual suspicions and failures in boiler pressure parts. The investigation generally consists of an on-site visit by a stress analysis engineer for inspection and selective nondestructive testing of the suspect component. If possible, a metal sample is removed for laboratory examination. After metallurgical and analytical evaluations, the probable cause with remedial recommendations are forwarded to the client in a detailed technical report. Table 1 presents a listing of some typical problems and failures found in boiler tubes, header and drum components, together with their associated failure mechanisms.

There has been a history in the industry, of internal bore hole and ligament cracking in several different headers on units operated in a cycling duty mode. References 2 and 3 address this subject in detail for an economizer inlet header. Figure 1 shows internal longitudinal cracks in the bore hole of a high temperature superheater outlet header.

MODIFICATIONS AND UPGRADES

One of the most important aspects of the Riley Condition Assessment program is its capacity to provide detailed recommendations on modificaitons and upgrading for safety, reliability, and availability purposes. Some of the major component that are candidates for such inspection/analysis include, but are not limited to the following:

High Temperature Superheater and Reheater Elements

These high temperature components are reviewed for sagging, distortion, support adequacy, flexibility, weld design, and material selection for the desired operation conditions.

The Riley design philosophy is to minimize the number of support ties and guides, as each weld-

TABLE 1
TYPICAL BOILER PRESSURE PART FAILURES

BOILER TUBES	
S.H./R.H. TUBE SWELLING AND RUPTURE:	HIGH TEMPERATURE CREEP
TUBE NIPPLE EXTERNAL CRACKING:	THERMAL EXPANSION FATIGUE
TUBE INTERNAL CRACKING:	THERMAL AND CORROSION FATIGUE
HEADERS	
ECONOMIZER INLET HEADER: INTERNAL CRACKING	THERMAL AND CORROSION FATIGUE
HIGH TEMPERATURE HEADER: INTERNAL CRACKING	CREEP-FATIGUE
HIGH TEMPERATURE HEADER: SWELLING	HIGH TEMPERATURE CREEP
HIGH TEMPERATURE HEADER: LOCAL BULGING	CREEP, THERMAL EXPANSION OR ABNORMAL EVENT
HEADER EXTERNAL LAMINATIONS:	FABRICATION DEFECTS
HEADER EXTERNAL CRACKING:	THERMAL SHOCK OR THERMAL EXPANSION
REHEAT INLET HEADER SAGGING:	SUPPORT PROBLEM, ABNORMAL EVENT OR OVERTEMPERATURE EXPOSURE
DRUMS	
INTERNAL SURFACE PITTING:	OXYGEN CONTROL IN FEEDWATER
INTERNAL LIGAMENT AND NOZZLE: CRACKING	THERMAL AND CORROSION FATIGUE
EXTERNAL NOZZLE WELD: CRACKING	THERMAL EXPANSION FATIGUE

ment is a potential source of failure. Scissor alignment tubes are recommended at predetermined locations in lieu of a series of slide guides. Where slide guides are required, a proven, state of the art guide is recommended. The current guide is designed to be better cooled and use less weldment with a procedure to minimize dissimilar weld joint stresses. In-house finite element programs are used to predict temperature profiles throughout the lug to tube interface. Figure 2 shows typical results that enable the proper lug material selection for given design conditions and associated temperature profiles.

Purchased piping software and in-house developed creep and fatigue programs are utilized to assess the overall tubing system. Thermal transients are considered in accordance with how the client intends to operate the unit. The results of these analyses enable the proper tube metal selections, with any geometric changes that are required to suit the design parameters i.e. adequate flexibility for cycling and proper materials for calculated temperatures.

During this analysis key ingredients are considered in the evaluations. The amount of internal and external scale is input into the analysis in order to predict the higher metal temperatures present from the scale effects. This in turn enables a more accurate assessment of expected tube life when combined with the known unit history and metallurgical findings. The extent of stainless steel recommended is given special attention to insure that the higher coefficients of expansion do not create an unbalanced system that promotes excessive distortion. The ability to predict creep effects has resulted in a trend to require shorter support spans on tube elements. These analyses are performed to insure that any modification will meet present day needs. The ASME Code has continued to derate the allowable stresses on some of the typically used low chrome molybdenum steels. Table 2 shows the significant reductions in allowables that were initiated in the mid 1960's and more recently revised in 1988. This effect on tube rupture life must be considered in any

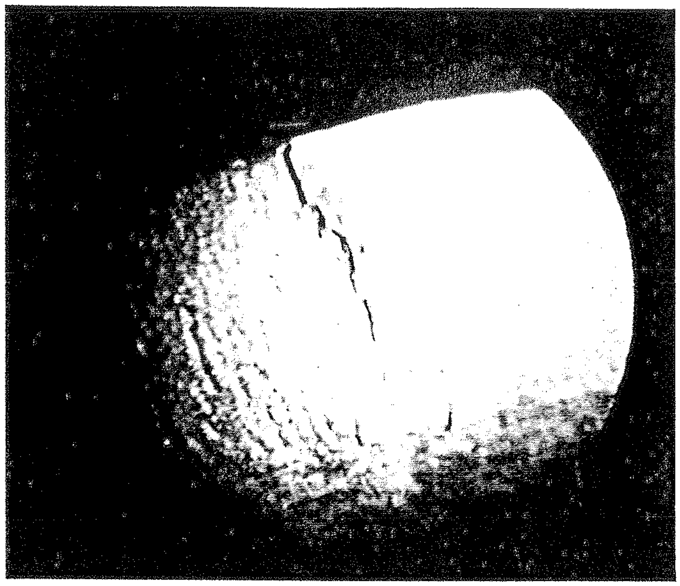
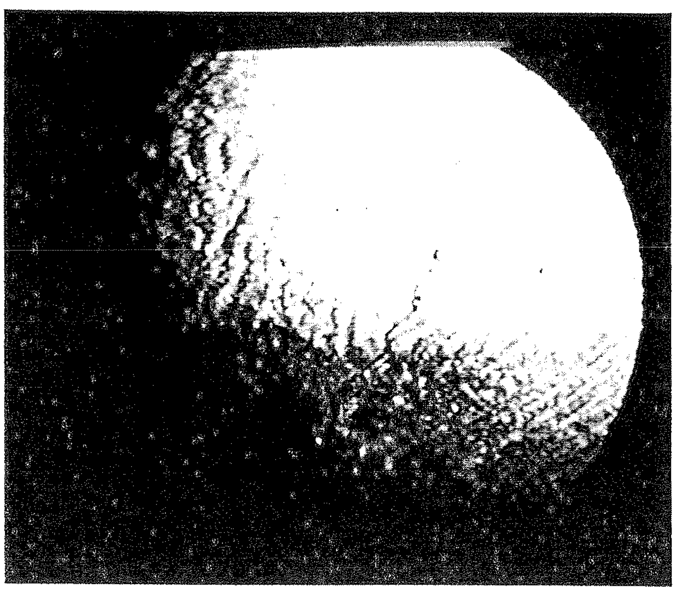
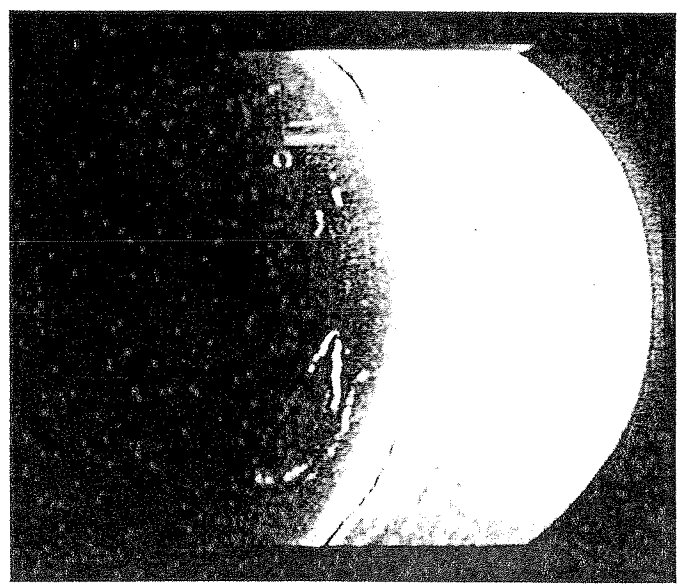


Figure 1: Portions of HTSH Outlet Header Cracking Reproduced from Inspection Videotape (Crack Magnified Slightly)





replacement modification or upgrade.

Element Penetrations and Seals/Tube Header Nipple Cracking

Many older units experience seal and tube to header nipple cracking. It is essential to provide a welded flexible seal at the roof line, with adequate tube flexibility from the seal to the header. These tubes are often analyzed by computer techniques for the historical conditions found (temperature, cycles, etc.), and rerouted as required for the intended future use. The method of welding the tube nipple to header is important to the overall success of obtaining the desired life. Weld profiles must be smooth and blend into the base metal. Consumable inserts are provided during the initial manufacturing of the header to allow for expansion and shrinkage during the welding process.

A very common type of pressure part failure is at the junction of a tube connector and header. Cracking, often leading to failure, has been found to exist at these locations, particularly initiating in the toe of the external attachment weld. This cracking is often associated with, but not restricted to high temperature components. It has been found to also exist in lower waterwall and economizer headers. For the common case of external tube nipple weld cracking, the most prevalent failure mode is fatigue induced by differential thermal expansion. This condition can sometimes be accompanied and aggravated by an overtemperature condition. Typically, the cracking will occur in a circumferential pattern on the outer portion (away from the header) on the tube side of the tube to header weld. Also, the weld cracking is more likely to occur in tubes at the end of a header and in the shorter, less flexible, inlet tubes, which are more susceptible to both the axial (header) and radial (tube) thermal expansion effects, which occur during startup, shutdown, restart and load swing events. Reference 5 addresses this subject in detail.

Buckstay/Windbox Attachments

These attachments are prime candidates for fatigue failures. Older buckstay attachment designs consisted of welding the tube directly to the structural member (see Figure 3 for typical cracking). Over time, fatigue cracks will propagate and fail at the tube. A new design is available using plates and better welding methods to resolve this problem.

Windbox seals are often too rigid for the way a unit is operated. A design study is often required for installing a nonrigid condition at the corner. All of these conditions have become more predominant

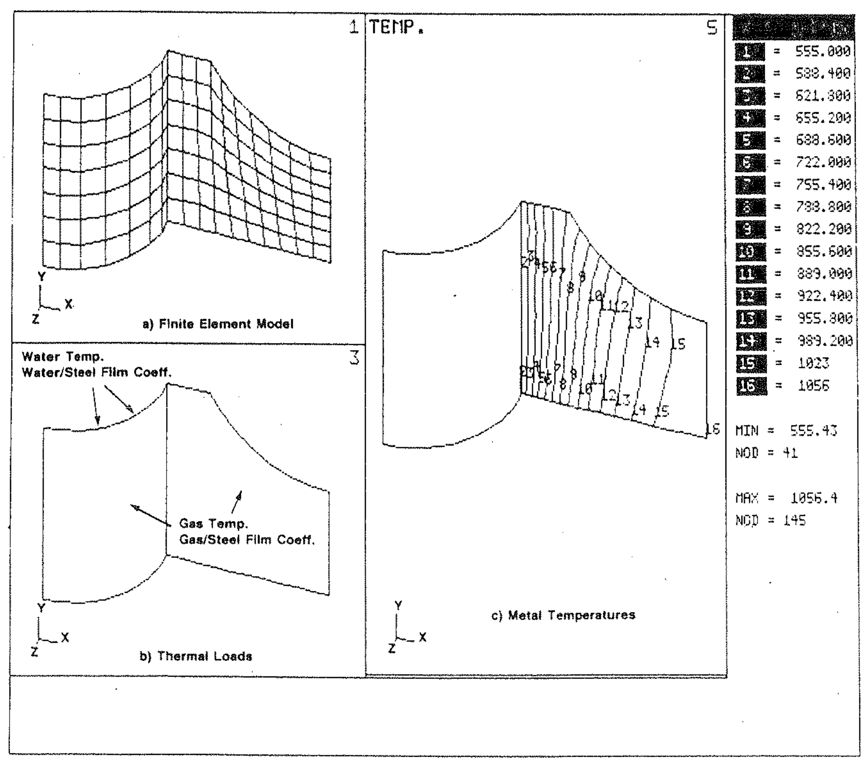


Figure 2. High Temperature Superheater Tube Support

TABLE 2
MAXIMUM ALLOWABLE STRESS VALUES (PSI)
FOR SA335 P11 SEAMLESS PIPE MATERIAL
FROM ASME CODE SECTION I

CODE EDITION	TEMPERATURE (F°) 750	800	850	900	950	1000	1050
PRE 1967	15,000	15,000	14,400	13,100	11,000	7,800	5,500
1967 TO 1987	15,000	15,000	14,400	13,100	11,000	6,600	4,100
1988	14,800	14,400	14,000	13,600	9,300	6,300	4,200

as the units are operated more and more in a cycling or peaking mode.

Header/Drum Cracks

The key areas of concern have been pointed out previously in this paper. To reiterate, cracking conditions have been found in the following critical areas:

- Economizer Inlet Header
- Primary S.H. Outlet Header
- HTSH & HTRH Outlet Headers
- Lower Hopper Headers
- Reheat Inlet and Outlet Pipes (seam welded pipe) Spray Stations
- Drum Nozzles

Each one of these components require a case by case review based on the inspection findings and analytical studies using the tools previously mentioned.

Recommended solutions are different for each component. In the case of the economizer inlet header, the thermal cracking condition is minimized through the addition of such items as a warm-up system during startup, lowering the ligament stresses, and relocating the header inside the unit. In the case of a primary superheater header, a simple material upgrade may be in order due to the reduction in material stress allowable as previously discussed. The high temperature outlet headers may be corrected through a series of changes, increased tube flexibility, upgraded materials/thicknesses, addition of moment restraints at the outlet connections, etc., if a redesigned replacement is necessary.

The drum nozzle cracking issue is of ultimate concern. Although more work is required to understand the cause, the condition is serious and must be addressed quickly. Simple repairs can be made at the time of detection, followed up by an Engineering study to provide a long term solution.

Low NOx Burners

The Riley Controlled Combustion Venturi (CCV) burner (U.S. Patent No. 4,479,442) was originally developed as a low-NOx coal burner for wall-fired boiler retrofit and new installation applications. Our experience to date includes both utility and industrial size installations with NOx reductions up to 50% below uncontrolled emission levels. In order to extend the performance of this low-NOx burner technology over a wider range of operating conditions, additional design improvements have been developed and implemented in recent years. These improvements have resulted in the following major benefits:

- Improved mechanical reliability and operability of the secondary air register.
- Reduced air side pressure drop requirements for wider retrofit application.
- Independent control of air flow and swirl with more efficient and reliable swirl generation.
- Additional NOx reduction.

The latest Riley CCV burner design is shown in Figure 4. The most recent development effort focused on incorporating a single actuator drive mechanism for the shroud which greatly simplified the burner front arrangement. Riley CCV burners

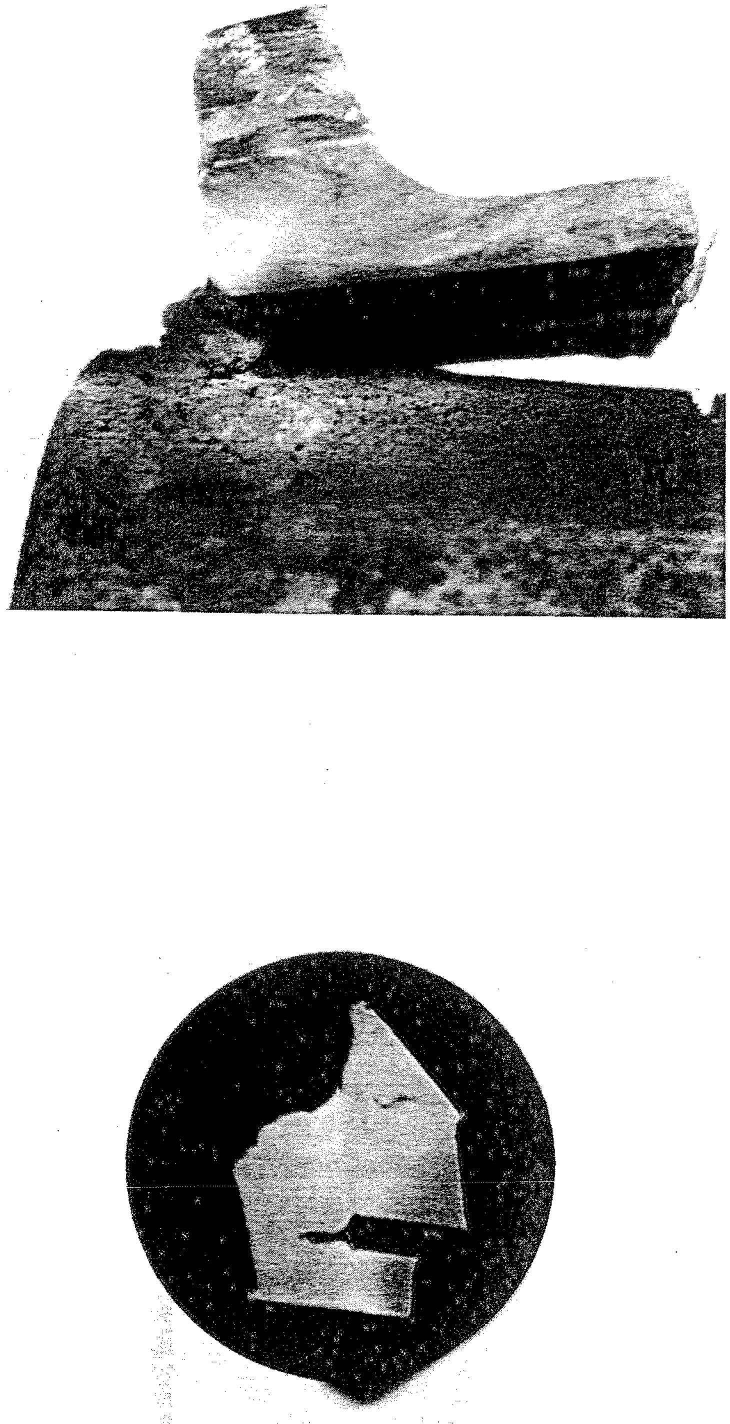


Figure 3: Buckstay Attachment Weld Failure.
Metallurgical Specimen of same in Lower Picture.

are now being proposed for a number of utility and industrial boiler retrofit applications both in the U.S. and Far East.

Mill System Upgrades

Riley utilizes an integraded system approach when reviewing coal pulverizing equipment, whether the milling system has atrita pulverizers or ball tube mills. Since each contract was designed under specific fuel conditions, and those conditions have probably changed with time, complete review from feeders through a systematic approach. Some current problem areas that customers need addressed are:

- Customer/OEM Interface
- Operator Training/Technical Expertise
- Carbon Loss Reduction
- Emission (NOx, CO)
- Unit Efficiency Improvements
- Mechanical Problems With Burners or other Equipment
- Ball Charge Materials

Riley believes that by understanding the impact that the fuel burning equipment has on the boiler can lead to successful and efficient operation under today's conditions.

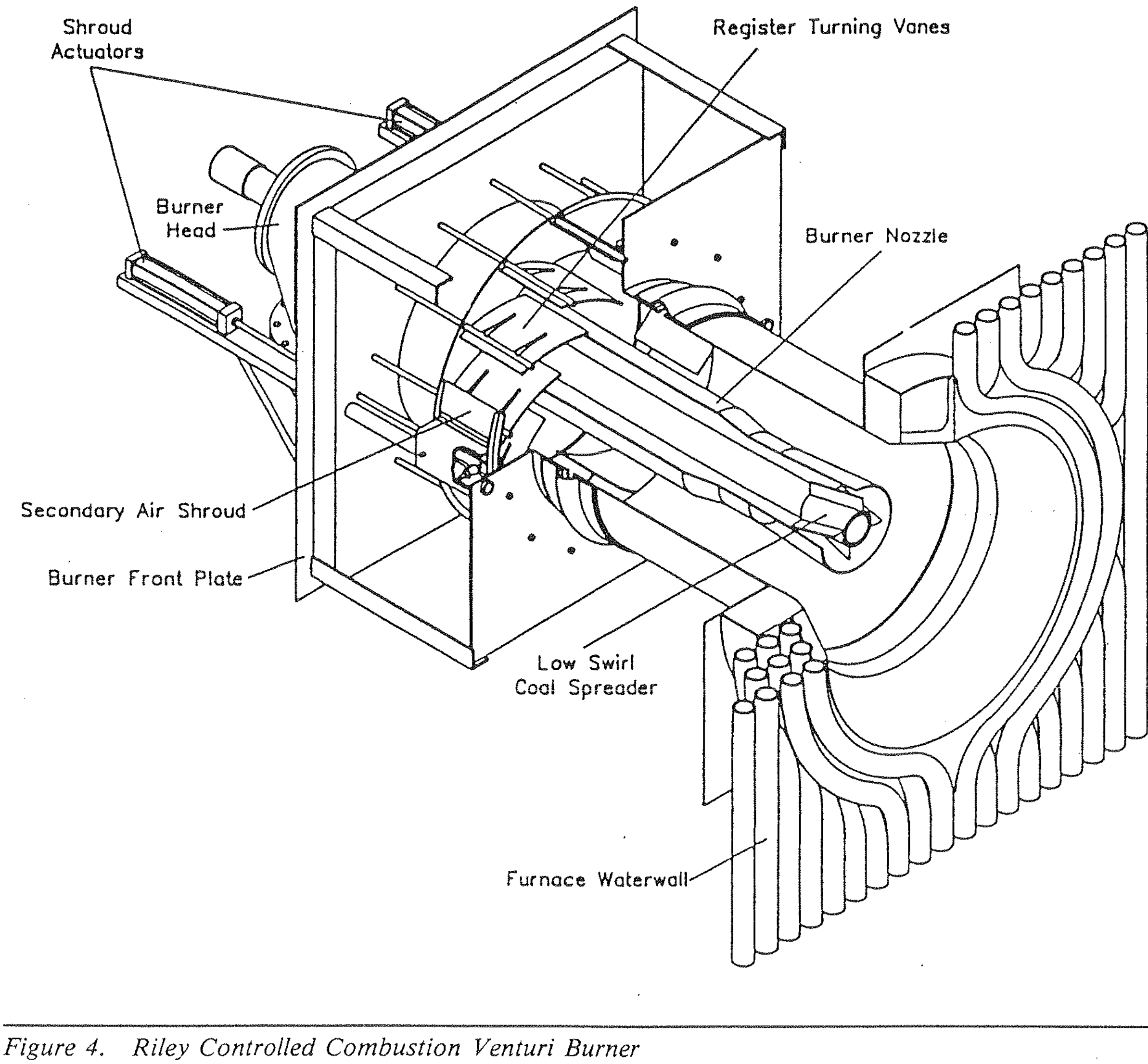


Figure 4. Riley Controlled Combustion Venturi Burner

SUMMARY

This paper has presented an overview of Riley Stoker's Utility Boiler Condition Assessment program. Typically, each program is tailored to suit the needs and requirements of our clients. We utilize state of the art analytical techniques, and destructive and non-destructive testing methods in our evaluations. This is combined with our in-depth experience in boiler inspecting and the vast design knowledge of an OEM, to provide an expert quality boiler assessment.

The main emphasis of this paper has been on unit safety and reliability. Thus, pressure part investigations and their associated enhancements form the basis of the Riley program. The boiler upgrades mentioned herein should be considered representative of our capabilities. These are expanded upon, as warranted by the inspection findings. For example, other critical areas given special consideration include, but are not limited to boiler casings, settings, refractories, expansion joints, piping, valves, hangers, sootblowers, fans, ducts, airheaters, and fuel burning equipment. Also, Engineering studies are provided to resolve any specific problems the client may have.

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