Boiler Fitness Survey for Condition Assessment of Industrial Boilers

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Abstract

In today's markets, reducing costs and optimizing the production of installed capacity is essential. The electric utilities have depended upon life extension of existing boilers since the early 1980s to meet generation needs. Similarly, general industry faced with competition and cost control are looking to extend the lives and in many instances upgrade the capacities of existing boilers. The Babcock & Wilcox (B&W) boiler fitness survey has proven to be an effective program for analyzing the condition of aging boilers. The extent of the fitness survey is geared to the level of cost and effort that will provide the plant owner with the information needed to make decisions for future operation of the boiler(s); as such, the survey can be tailored to the needs of the customer. The following describes the method of developing the scope of the boiler fitness survey as well as the key components, damage mechanisms, nondestructive examination methods, and techniques for determining boiler remaining useful life.

Introduction

For many years condition assessment and life extension programs have been common in the electric utilities. Much of the emphasis in the utility generating stations has been on components with expected finite lives where degradation and failure are associated with creep and creep-fatigue. Components such as steam outlet headers, main steam and reheat steam piping, and steam turbines are all subject to eventual material failure from operating at high temperatures and stresses. As a general class, industrial boilers typically operate at much lower temperatures and pressures. As a result, the life of these boilers is not necessarily defined by a finite material life. In fact there are numerous examples of very old boilers (>50 years operating life) which can still be operated. Many times these older boilers are retired for reasons other than reliability or safety.

Today, the need to establish formalized programs for assessing the condition of boilers in industrial plants is becoming increasingly important. Industrial installations are under the same pressures to reduce costs as are the electric utilities. Additionally, boiler upgrades and capacity increases are potential lower cost options for plants anticipating expansions. Babcock & Wilcox's boiler fitness survey is a comprehensive program for assessing the integrity and fitness of aging boilers. Boiler fitness surveys combine the knowledge of B&W's field service engineering with the specialized inspection technologies and experience that have been developed by B&W for boiler condition assessment. Presented in the following paper is the program and methods recommended by Babcock & Wilcox for the assessment of industrial boilers.

Industrial versus Utility

The condition assessment program for industrial boilers is not unlike the approach used for the electric utilities, except for the primary mechanisms of failure and the inspections methods that are used. Industrial boilers come in all shapes and sizes and can be found in a variety of industries and institutions. For purposes of condition assessment classification, industrial boilers are those units designed for outlet steam temperatures of 900 F (482 C) or less with design pressures that typically do not exceed 1500 psig (104 bar). By contrast, the modern era utility boiler is designed for outlet steam temperatures of 1000 F to 1050 F (538 to 566 C), with design pressures ranging from 1800 to 3850 psig (124 to 265 bar). Utility class boiler designs can be found in non utility plants; however, the discussion presented below will focus on the industrial class boiler designs.

Condition Assessment Considerations

In the planning of a condition assessment program it is important to consider the objectives for the boiler. For example, the scope of the assessment and the remaining life analysis would be more extensive if the goal for the boiler is 20 years additional operating life as opposed to 5 years; or if the purpose of the assessment is to decide the merits of spending capital on a major upgrade versus installing new capacity. Typical questions to be addressed in the planning of a condition assessment program include:

- How many years of service are required from the boiler?
- At what capacity will it be operated?
- Will it be base loaded or cycled regularly?
- Are upgrades under consideration and, if so, what systems may be upgraded or replaced?

Planning the Scope of the Boiler Fitness Survey

The complexity of inspections and testing to support a boiler fitness survey can vary. The scope depends on several factors such as the boiler design type, design temperatures and pressures, materials, fuels, age, unit history and future plans for the boiler or plant. B&W follows a multi-level approach in the planning of the survey scope which is similar to the approach developed by the Electric Power Research Institute (EPRI) for utility boilers.[1] Basic to all levels of the fitness survey is a comprehensive inspection by an experienced B&W Field Service Engineer. A first level survey depends on minimal if any testing or nondestructive examination (NDE). Level II includes NDE testing with little material sampling although tube samples may be included. Level III surveys incorporate material testing, engineering studies and more extensive analysis in support of the assessment. Proceeding from a level I effort to a level III survey is dictated by the objectives of the project, i.e., the scope of data needed to predict future operation to the extent needed by the owner. Typical multi-level activities are as follows.

Level I

- Evaluate past operating and maintenance history.
- Identify any critical components on basis of history, experience with similar boilers, and objectives for future of unit.
- Perform complete visual inspections of all accessible areas of the boiler and/ or auxiliaries - photo-document problem areas as needed.
- Identify the root cause of damage found to the limits of level I survey.
- Develop a final boiler fitness report with recommendations.

Level II (in addition to items in Level I)

- Establish the outage inspection and testing plan.
- Define support requirements for the inspections including any materials that may be needed.
- Assess operation - may include hot walk down of boiler and piping, and data gathering to evaluate performance of auxiliary equipment.
- Implement inspection and testing plan. May include tube samples for basic condition assessment analysis.
- Perform preliminary life estimates and provide recommendations for immediate action as needed.
- Prepare for follow up operational testing as required/ planned.
- Estimate remaining life - analyze data and inspection results.
- Implement operational testing if required.

Level III (in addition to Levels I and II)

- Perform engineering analysis such as piping stress analysis, finite element analysis, boiler performance/upgrade analysis.
- Remove materials for laboratory analysis, i.e. boat samples, tube materials for accelerated creep rupture tests, fatigue tests, etc.
- Perform specialized site testing such as strain measurements, support load testing, etc.

After the conclusion of the condition assessment program, the plant owner utilizes the results in the planning for the plant – whether long range or short range. The information may simply aid in the planning of reinspection and regular preventive maintenance to ensure reliable steam production. The assessment may be used to define the scope of a major upgrade or plant overhaul by determining what components need replacement.

Critical Systems and Components

The critical components or systems can be prioritized by the impact they have in the following categories.

1. Safety - anything with the potential to injure personnel or damage property.
2. Reliability - failures that could lead to forced outages and loss of production.
3. Performance - effects on unit efficiency, emissions, etc.

In a comprehensive boiler evaluation, items such as the safety valves, burners, flame safety system and combustion controls should be given high priority because they are directly related to the safe operation of the boiler. These systems and components must be maintained, calibrated and tested as part of the normal operation of the boiler. Many times the boiler fitness survey will address these systems to determine their current acceptability to modern standards such as National Fire Protection Association (NFPA)[2] guidelines for safe firing of the burner(s). When included in the scope of the assessment, B&W Field Service performs audits of controls and safety systems. The service engineer can also do boiler performance testing to evaluate unit efficiency; this can be of particular value when engineering studies are done to evaluate options for unit upgrades.

Generally, the critical components that are the focus of inspections and NDE in a level II survey are those components whose failure will directly affect the reliability of the boiler. Components that comprise the pressure parts of the boiler are given special attention since failure leads to forced outages and lost steam production. These critical pressure parts include:

- Drums - steam, lower, uptake, downtake, etc.
- Headers - both steam and water
- Tubing - superheater, boiler or generating bank, waterwall, economizer
- Piping - steam and feedwater
- Deaerator - may have special safety concerns
- Attemperators - sometimes called desuperheaters

Components that are more likely to have adverse effects on boiler performance as they deteriorate with age include:

- Air heaters - recuperative (tubular), regenerative (Ljungstrom), steam coil
- Fans - induced draft, forced draft, primary air (pulverized coal firing)
- Burners
- Fuel preparation equipment (especially coal firing, i.e. pulverizers)
- Boiler settings such as casing and BRIL (brickwork, refractory, insulation and lagging)
- Structural supports

Nondestructive Examinations (NDE)

NDE can be an important part of the boiler fitness survey. NDE is done to obtain sufficient data to allow the engineer to assess and make decisions regarding the integrity of the component. The choice of NDE methods will depend upon location and type of potential damage as well as the limitations caused by the arrangement and geometry of the component itself. NDE methods that have been used by B&W on industrial boilers are visual examination (VE), magnetic particle testing (MT) and wet fluorescent magnetic particle testing (WFMT), liquid dye penetrant testing (PT), ultrasonic testing (UT), remote field eddy current testing (RFEC), electromagnetic acoustic transducer based testing (EMATs), metallographic replication (MR), and acoustics or acoustic emissions (AE) testing. Radiography, an important NDE method for field testing of welds, is primarily used to test welds following boiler erection or repair and is not normally used for fitness surveys.

NDE methods have advantages and disadvantages and it is important to select the correct method for each component. The extent that an NDE method can be used depends on the access to the component as well as surface preparation. Described below are the types of problems found in the various components as well as the recommended NDE methods. In general, visual examination, the most basic of NDE, is done for all components. It is common to photo-document the inspection to provide a permanent record in the report. Internal inspections are frequently done by video probe and recorded on tape.

Drums: The steam drum is the single most expensive component in the boiler. Consequently, any assessment program must address the steam drum as well as any other drums in the convection passes of the boiler. In general, problems in the drums are associated with corrosion. In some instances, where drums have rolled tubes, rolling may produce excessive stresses that can lead to damage in the ligament areas. Problems in the drums normally lead to indications that are seen on the surfaces – either ID or OD. *Assessment: Inspection* and testing focuses on detecting surface indications. The preferred NDE method is WFMT. Because WFMT uses fluorescent particles which are examined under ultraviolet light it is more sensitive than dry powder type MT and it is faster than PT methods. WFMT should include the major welds, selected attachment welds and at least some of the ligaments. If locations of corrosion are found then ultrasonic thickness testing (UTT) may be performed to assess thinning due to metal loss. In rare instances metallographic replication may be performed. Replication is done by polishing the surface of the drum to a mirror finish, etching the polished surface with a nital acid, and then lifting an image of the metal surface by applying a softened acetate tape (the replica). The procedure, analogous to finger printing, allows the metal grain structure to be examined under a microscope.

Headers: Boilers designed for temperatures above 900 F (482 C) can have superheater outlet headers that are subject to creep – the plastic deformation (strain) of the header from long term exposure to temperature and stress. For high temperature headers, tests can include metallographic replication and ultrasonic angle beam shear wave inspections of higher stress weld locations, as well as B&W's bore hole Hone & Glow® test of ligaments to detect damage associated with creep and creep-fatigue. However, industrial boilers are more typically designed for temperatures less that 900 F (482 C) such that failure is not normally related to creep. Lower temperature headers are subject to corrosion or possible erosion. Additionally, cycles of thermal expansion and mechanical loading may lead to fatigue damage. *Assessment:* NDE should include testing of the welds by MT or WFMT. In addition, it is advisable to perform internal inspection with a video probe to assess waterside cleanliness, to note any buildup of deposits or maintenance debris that could obstruct flow, and to determine if corrosion is a problem. Inspected headers should include some of the water circuit headers as well as superheater headers. If a location of corrosion is seen then UTT to quantify remaining wall thickness is advisable.

Piping – Main Steam: For lower temperature systems the piping is subject to the same damage as noted above for the boiler headers. In addition the piping supports may experience deterioration and become damaged from excessive or cyclical system loads. *Assessment*: The NDE method of choice for testing of external weld surfaces is WFMT. MT and PT are sometimes used if lighting or pipe geometry make WFMT impractical. Non drainable sections such as sagging horizontal runs are subject to internal corrosion and pitting. These areas should be examined by internal video probe and or UTT measurements. Volumetric inspection, i.e. ultrasonic shear wave, of selected piping welds may be included in the NDE; however, concerns for weld integrity associated with the growth of subsurface cracks is a problem associated with creep of high temperature piping and is not a concern on most industrial installations.

Feedwater Piping: A piping system often overlooked is feedwater piping. Depending upon the operating parameters of the feedwater system, the flow rates, and the piping geometry, the pipe may be prone to corrosion or flow assisted corrosion (FAC). This is also referred to as erosion-corrosion. If susceptible, the pipe may experience material loss from internal surfaces near bends, pumps, injection points and flow transitions. Ingress of air into the system can lead to corrosion and pitting. Out-of-service corrosion can occur if the boiler is idle for long periods. *Assessment*: Internal visual inspection with a video probe is recommended if access allows. NDE can include MT, PT or WFMT at selected welds. UTT should be done in any locations where FAC is suspected to ensure there is not significant piping wall loss.

Deaerators: Overlooked for many years in condition assessment and maintenance inspection programs, deaerators have been known to fail catastrophically in both industrial and utility plants. The damage mechanism is corrosion of shell welds which occurs on the ID surfaces. *Assessment:* Deaerators' welds should have a thorough visual inspection. All internal welds and selected external attachment welds should be tested by WFMT.

Attemperators: The spray flow attemperator, a device for controlling superheater outlet steam temperature, is normally located in the piping system between the primary (1st stage) superheater outlet and the secondary (2nd stage) superheater inlet. The attemperator is subject to failures associated with thermal fatigue cracking of its components and welds. Since it is in a closed loop of the boiler, failures may go undetected until pieces of the attemperator lead to other damage, such as superheater tube failures. In addition to the B&W attemperator, condensing-type attemperators (commonly called "sweetwater condensers"), have experienced failures associated with fatigue. These steam temperature control systems should also be part of the boiler fitness survey testing. *Assessment:* For the B&W spray attemperator, inspection is recommended by removal of the spray head assembly. The spray head is inspected visually and tested nondestructively by MT/PT methods. Following removal of the spray head from the body of the attemperator, the attemperator thermal liner can be internally inspected with a video probe. Sweetwater condensers are subject to damage primarily from water hammer leading to cracks in the condenser shell. All welds on the internal surface of the condenser shell as well as shell connections and auxiliary piping should be inspected by MT, PT methods. If internal access to the condenser shell is not possible then ultrasonic angle beam shear wave testing can be done to detect shell cracking.

Tubing: By far the greatest number of forced outages in all types of boilers are caused by tube failures. Failure mechanisms vary greatly from the long term to the short term. Superheater tubes operating at sufficient temperature can fail long term (over many years) due to normal life expenditure. For these tubes with predicted finite life, B&W offers the NOTIS® test and remaining life analysis. However, most tubes in the industrial boiler do not have a finite life due to their temperature of operation under normal conditions. Tubes are more likely to fail because of abnormal deterioration such as: water/steam-side deposition retarding heat transfer, flow obstructions, tube corrosion (ID and/or OD), fatigue and tube erosion. *Assessment:* Tubing is one of the components where visual examination is of great importance because many tube damage mechanisms lead to visual signs such as distortion, discoloration, swelling or surface damage. The primary NDE method for obtaining data used in tube assessment is contact UTT for tube thickness measurements. Contact UTT is done on accessible tube surfaces by placing the UT transducer onto the tube using a couplant, a gel or fluid which transmits the UT sound into the tube. A new measurement technique developed by B&W under an EPRI-sponsored project is the FST-GAGE™ [3] which utilizes EMAT, ElectroMagnetic Acoustic Transducer technology. EMAT utilizes electromagnetic induction to produce the ultra frequency pulse in the tube; this eliminates the need for a couplant. Contact UTT and the FST-GAGE have very accurate measurement capability which gives a measurement within plus or minus 0.005 in. (0.127 mm). The FST-GAGE's UT accuracy without need of couplant makes it excellent for scanning tubes where isolated damage is a concern. Variations on standard contact UTT have been developed due to access limitations. Examples are IRIS-based techniques (internal rotating inspection system) in which the UT signal is reflected from a high RPM rotating mirror to scan tubes from the ID - especially in the area adjacent to drums; and B&W's immersion UT where a multiple transducer probe is inserted into boiler bank tubes from the steam drum to provide measurements at four orthogonal points. IRIS and immersion UT require tubes to be flooded with water. Remote field eddy current (RFEC) probes have also been developed for internal inspection of tubes. RFEC has the advantage of not requiring a tube to be flooded or have a column of water but it has the disadvantage of not providing the measurement accuracy of UT. Tube inspection systems based on laser profilometry have been developed that provide for inspection and mapping of tube surface topography. These systems can be advantageous in the assessment of pitting.

Remaining Life

Various methods have been developed for assessing the remaining useful life (RUL) of key boiler components. For thin wall high temperature components, such as superheater tubing, failures are associated with creep rupture. Analysis of RUL is done using well established life fraction theories and creep-rupture material data bases.[4] For heavy section components such as headers and piping that operate at high temperature, failures are characterized by the initiation and growth of cracks under the influence of creep and/or fatigue. Analysis methods have also been developed which consider time dependant fracture mechanics (TDFM) and that allow quantification of component life based on crack growth.[5] These creep related life prediction methods are not normally needed for the industrial boilers because of their lower operating temperatures.

For the industrial boiler the most common tool for RUL assessment is analysis of corrosion and erosion rates and comparison of actual component wall thicknesses versus American Society of Mechanical Engineers (ASME) Boiler Code calculated minimums. Since tube life and tube failure tend to be the major cause of forced outages in aging boilers, RUL of low temperature tubes is a large part of industrial tube RUL assessment. In 1985, B&W developed a guideline that boiler owners could use for setting a flag or bench mark thickness in assessing tube wall measurement data. The guideline, released as B&W Plant Service Bulletin PSB-26, Tube Thickness Evaluation Repair or Replacement Guideline, was intended to help boiler owners by giving them guidance, while not being overly conservative. For many boilers, tube failures most often have economic consequences such that the owner/operator will operate existing components as long as it is economically justified compared to the cost of replacement. For these units, many years of component life may exist in the margin between ASME Code minimum and the absolute minimum where failures occur. For water-cooled tubes, B&W guidelines established 70% specified wall thickness for the flag point below which the tube should be replaced. This guideline assumes that specified wall is approximately ASME minimum – a valid assumption unless the original design included tube wall thickness with a corrosion allowance over and above ASME minimum. The guidelines are set so that tube replacement is planned before tube stresses reach the yield strength of the tube. The PSB flag point guideline only applies to boilers where tube leaks occur internal to the boiler settings as a result of fire-side wall loss from erosion and corrosion, and tube failures do not pose an unusual safety risk. Failures that occur external to the boiler setting from mechanisms such as acid attack or corrosion fatigue must be treated with greater urgency and caution if the tube leak can cause injury to personnel. In addition, special circumstances dictate necessarily conservative guidelines. For example, process recovery boilers in the pulp and paper industry can experience an explosive smeltwater reaction if tube leaks occur in the water wall tubes. For these boilers, tube replacement is recommended when the tube wall drops below ASME minimum thickness.

Summary

Extending the life of industrial boilers which operate at lower temperatures and pressures is a viable option to support plant steam production needs. The boiler fitness survey has proven to be an effective program for determining the current condition and remaining useful life of aging industrial boilers. Extensive visual examination by an experienced B&W Field Service Engineer complemented by NDE allows comprehensive assessment and provides the owner with the information needed to make long range decisions regarding the subject boiler.

References

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