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the Conduit

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High Energy Piping Evaluation, Part 3 of 3

By Jonathan D McFarlen
The full article can be seen in the COMBINED CYCLE Journal, 1Q/2009.

In the last installment of *High Energy Piping Evaluation*, damage mechanisms are discussed. Furthermore, susceptible areas for a particular mechanism are mentioned, as well as, appropriate non-destructive testing methods.

Damage Mechanisms
The following table shows a compilation of damage mechanisms based upon industry experiences. You will note that locations where the particular mechanism is more likely, are provided as well as corresponding non-destructive testing methods. Each damage mechanism is discussed in further detail in the following table.

Plastic Deformation (i.e., deformation) can occur in straight runs of piping, bends, sweeps, hanger attachments and associated structural support. A thorough walk-down of the piping systems can be used to visually detect any significant deformation in the piping or hangers (specifically hanger rods and pipe attachments). Areas suspected to have deformation can be checked using measuring devices such as calipers or straight edges. Welded hanger attachment lugs on deformed pipe or pipe hangers should be checked for cracks via magnetic particle testing. Deformation may also induce draining problems that can promote internal corrosion.

Table 1. Damage Mechanism Assessment

Mechanism	Location(s)	Detection Method(s)
Plastic Deformation	Straight runs, bends, sweeps, hangers and associated structural steel	VT
High Cycle Fatigue	- Branch line welds	MT
Low Cycle Fatigue (Thermal)	- Circumferential welds	VT, MT, UTSW
External Corrosion	- Piping external surface - Hangers	VT
External Corrosion Fatigue	- Pipe external surface - Hanger attachments	VT with subsequent MT
Internal Corrosion Fatigue	- Pipe internal surface at low drain points	Remote VT with Subsequent UTSW
Creep Rupture	- Circumferential welds (External) - LSW piping - RT plug welds	MT, Replication, Cryo-cracking
Creep-Fatigue	- Circumferential welds (External) - RT plug welds	MT
Flow-Accelerated Corrosion (FAC)	Single liquid phase or two phase bearing piping	UT

In this Issue

High Cycle Fatigue (HCF) can cause cracking in particular at branch connections resulting in leaking. Failures of this type would result in down time but would not likely be catastrophic in nature as leaking would be more likely than rupture. As a precautionary measure, insulation at line branches (fabricated and fittings) can be stripped so that magnetic particle testing can be used to detect any external cracking.

Low Cycle Fatigue (LCF) is a mechanism most associated with units that cycle often. LCF cracks are likely to initiate at geometrical steps. An example location for LCF to occur would be at a circumferential weld with the same pipe ODs but different pipe IDs. Even though a tapered weld joint prep may have been specified, inspection of stepped circumferential welds would be prudent. Hanger attachment lugs would also be areas where LCF may occur and they should be inspected. Visual examination and magnetic particle testing would be the normal inspection methods for external geometrical discontinuities. Ultrasonic shear wave testing could be used to identify cracks at internal discontinuities.

External corrosion of the piping (under insulation) and on hangers can facilitate other damage mechanisms - in particular, corrosion fatigue. Visual examination of the piping and associated supports can determine if corrosion is occurring. Often,

(Continued on page 2)

corrosion can be detected by oxide staining of the protective insulation lagging. Areas displaying notable oxide staining, which cannot be attributed to another source, should be stripped and inspected further. Hanger components displaying thick oxide layers should be inspected after removal of the thick oxide and evaluated for continued service.

External Corrosion Fatigue - External corrosion, pitting in particular, can serve as a nucleation site for fatigue cracking. Areas on piping and support hangers observed as having significant external corrosion should have all oxide removed followed by subsequent grinding to smooth the area. Magnetic particle testing should be used to detect any cracking.

Internal Corrosion Fatigue can result due to insufficient draining particularly during shutdown periods. Pooled condensate can promote local corrosion (i.e. pitting) that can eventually initiate fatigue cracking. Remote visual examination via borescope can be utilized to internally examine the suspect piping.

Creep Rupture is a damage mechanism that affects engineering materials operating at elevated temperatures. Chrome-moly low alloy steel piping operating at temperatures above 900°F introduce creep as a damage mechanism of concern. Creep occurs in three regimes. Stage 1 creep is rapid and occurs in the first 10,000 hours of service. In Stage 1, the piping system relaxes and residual stresses from fabrication are relieved. Furthermore, the piping system will tend to take a permanent "set". During Stage 2, the pipe grows in diameter and length. The rate and total expansion is dependent upon stress level, temperature, and time. Creep (especially Stage 2) is predictable and can be calculated using various empirical relationships such as Larson-Miller, Manson-Haferd or the Omega method. In Stage 2 creep, there are some microstructural features, such as the formation of grain boundary voids and linked voids, that can be monitored, but the relationships are, for the most part, imprecise. Stage 3 creep occurs late in the life of the component and it is characterized by micro-cracking, rapidly progressing macro-cracks and eventual rupture. Circumferential welds can be checked externally by magnetic particle testing and verified by replication. Cryogenic cracking is the most reliable test method for identifying creep damage in longitudinal seam welded (LSW) pipe. Cryogenic cracking requires removal of plug samples from the seam weld followed by subsequent repair.

Creep-Fatigue is a combination of fatigue loading while at elevated temperatures when creep damage is accumulating. Creep-fatigue is commonly found at highly restrained joints such as socket welds or at fully restrained attachments. Creep-fatigue is also possible at radiograph plugs that have been secured using austenitic (stainless steel) weld fillers. The austenitic/ferritic joint has a differential thermal expansion mismatch that can lead to creep-fatigue damage.

Flow-Accelerated Corrosion (FAC) produces rapid thinning in liquid or two phase bearing piping. Failures typically occur at or just downstream of fittings such as elbows, valves, or tees where turbulence is produced. FAC is well understood and establishing a program to mitigate FAC is fairly straight forward but unfortunately too lengthy to discuss at this time. (See Conduit, September 2006, page 1, *Finding FAC in HRSGs* by Ron Lansing.)

The initial evaluation step of a high energy piping system, or any boiler external piping system, is rather straightforward. Keeping a recorded log of a piping system's hot and cold hanger readings, along with general observations regarding the condition of the piping and its associated supports is a task that plant and mill personnel can independently perform. Following the visual inspection and hanger survey, several decisions may be required regarding hanger adjustments, hanger testing, stress analysis, and non-destructive testing. Hopefully, with the information presented in this series, plant and mill personnel will feel comfortable implementing some or all of these actions. In addition, by having an understanding of the potential damage mechanisms, and plant personnel will have better insight while performing visual inspections and hanger surveys. Furthermore, an understanding of these damage mechanisms should help in their detection.

Contact the Authors

Jon McFarlen, 512-407-3773
jon_mcfarlen@mmengineering.com

Max Moskal, 708-784-3564
max_moskal@mmengineering.com

Ron Munson, P.E., 512-407-3762
ron_munson@mmengineering.com

John Molloy, P.E., 512-407-3751
john_molloy@mmengineering.com

News and Upcoming Events

ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA
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Dave Daniels of M&M Engineering Associates, Inc. will be presenting a paper on Under -Deposit Corrosion Mechanisms and presenting training sessions on Boiler Water Chemistry following the regular conference sessions at the International Water Conference in Orlando, Florida, October 4, 2009 to October 8, 2009.

Forensic Investigation of a Gas Turbine Event

Part 3 of 3

By Ron Munson, P.E. and John Molloy, P.E.

This is the third part of a multi-part article that appeared in previous issues of the Conduit. The full article can be seen in the COMBINED CYCLE Journal, 3Q/2007.

In the first part of this article featured in a previous edition of the Conduit, the initial actions to take when investigating a gas turbine (GT) event were discussed. Initial documentation, preferably in the form of photographs and video, as well as interviews with the operators and key personnel are important to the investigation. Preservation of the remains is also critical in determining the root cause of the event.

The second part of the article focused on the steps for determining the proper level of investigation as well as composing the Root Cause Analysis (RCA) Team. The 3 levels of investigation include a level one investigation which is focused on the mechanistic level of damage; level two which focuses on the determination of cause; or level three investigation which is most difficult and costly, and should ultimately provide the root cause of the failure.

Typical members to be included when compiling the RCA Team include the Owner, the OEM, third parties hired by the owner and/or the insurance carrier.

Many GT loss events are not unique. Other machines have had similar or even identical failures. The lessons learned from these similar failures can greatly streamline the efforts of the RCA team. However, it is important not to leap to conclusions based upon someone else's evaluation on a similar but not identical piece of equipment. The RCA process must be carefully conducted and fully completed before comparisons are drawn. However, if two or more independent studies reach similar conclusions, the degree of certainty improves.

The next step in the process is research and data mining. There is information on GT loss events available to interested parties. User groups are the best source for sharing information, but it must remembered that this be done discreetly and ethically. Some research organizations such as the Electric Power Research Institute (EPRI) have chartered sponsor groups on generic fleet problems. Other sources of information include repair organizations and depots. Retired OEM engineers are also good sources for data and expertise, and make valued members of RCA teams.

OEMs usually issue information letters to the owners concerning generic or fleet issues affecting machines. It is always prudent to review the letters and determine if an information letter is relevant to the failure under investigation. In some instances an owner has received an information letter, but has not implemented the directive. The relevance of this non-compliance must be weighed as it pertains to the impact on the failure event.

Next, it is important to separate Cause versus Effect. The first look at a failed turbine is often confusing. The often catastrophic nature of these failure events leads to a jumbled mass of parts and debris. It is a daunting task to sort the sequence of events from an initial triage. The following points will aid in assessing the damage:

Think Front to Rear. Turbine airflow will sweep liberated debris to the rear of the engine, creating an increasing cascade of damage. The failure often, though not always, will begin at the front or near the front of this damage. Usually damage originating in a row or stage can and will impact the preceding stage by debris being propelled forward. A good example is the liberation of a second stage blade airfoil. It would be knocked forward into the trailing edge of the second stage vane, leaving impact damage in front of the original failed stage.

Machine Inputs. It is always important to understand what is entering the GT. The following are important:

- Air, filtered but not pure. While generally filters are effective, some particles will pass around or through the filter into the machine. This is especially true of volatile substances contained in atmospheric water vapor. Because a massive volume of air passes though the turbine, even a low concentration of

Figure 1. Power turbine failure exhibits considerable collateral damage.

contaminants translates into a large quantity of particulates entering the engine. Determination of filter condition is vital to this end.
- Fuel. Variation in fuel composition and properties can affect combusted dynamics and acoustic events. If the fuel quality or composition is suspect, often there are analytical data available for the fuel source.
- Lube oil. Substandard or contaminated oil can affect the integrity of the hydrodynamic seal, leading to premature bearing failures.
- Water for fogging, evaporative cooling, NOx control, or thrust augmentation can adversely impact compressor performance and damage the leading edges of compressor blades in the first few stages. Fogging and thrust augmentation also can affect the flow dynamics in the air path and lead to resonant-frequency shifts of the blade harmonics. Injection of water may lead to the buildup of an electrostatic charge that can cause bearing failure.
- Steam for NOx control may not be pure and can cause corrosion.

Unintentional Inputs. Turbomachinery does not like free objects in the flow path. Objects either foreign (unintentionally left in machine) or domestic (parts liberated by metal fracture) can cause failures, usually catastrophic. There are two ways to look for evidence of FOD (foreign object damage) or DOD (domestic object damage).

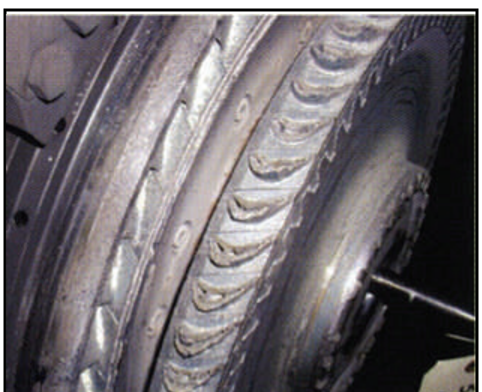

Figure 2. Life exhaustion caused the blade failure that wiped out this turbine.

One method is to sort through debris recovered from inside the machine and in the exhaust. This is time consuming and rarely successful. Foreign objects usually are ground up and obliterated by the rotational motion of the turbine. Domestic objects cannot be differentiated from accident debris.

Another method is to examine the airfoils just forward of the catastrophic damage to look for impact marks, which can be examined for geometric form to match suspect objects. It is also possible to examine the marks in an electron microscope to check for metal transfer between the offending object and the damaged component. The transferred metal usually can be matched to a DOD or FOD component.

Physics Matters. Often a specialist will focus on his area of expertise and not see an obvious detail. Physics matters! There are several points worth remembering, including the following::
- Hot metal expands.
- Gas flows from a region of high pressure to one of lower pressure.
- Rotating parts do not like debris.
- Compressed air gets hot.
- A filtration efficiency of 99.7 % means that there still is 0.3 % contamination.
- GT materials heated above 2600°F melt without cooling and protective coatings.
- Liberated parts cause increasing damage as they move aft through the engine in the direction of airflow.
- Unbalanced rotors rub the casing.

The Metal Does Not Lie (but it only tells part of the story). A detailed examination of the fracture surfaces by an experienced metallurgist usually can identify the initial damage mechanism for a GT. Generally, the initial component failure will have experienced a progressive damage mechanism such as creep or fatigue; secondary damage will have different mechanisms - such as ductile overload or cleavage. It is prudent to evaluate all fractures especially those forward of the catastrophic damage. Analysis of the data may involve many tasks. A typical investigation may include:
- Metallurgical laboratory analysis.
- Finite-element modeling and stress analysis.
- Analytical flow modeling.
- NDE of like or sister equipment.
- Apparatus testing.
- Review of parts pedigree, including tracking of third party repairs.

When all phases of the investigation are complete - including laboratory examination, mechanical analysis, records review, witness statements, and visual observations - a failure scenario should be postulated. This should be postulated in a suitable forum for discussion by the RCA team. This must be done before a final report is written. All data and observations should be reviewed critically. If all pieces of the failure puzzle do not fit together, there are two possibilities:
- The theory of failure is wrong or incomplete.
- The input data are wrong.

In the end, the various analyses must converge to the same conclusions.

Inspection and Repair of Batch Digesters
Part I of 3

By Max Moskal

Most Kraft batch digesters in North America were constructed from carbon steel prior to 1980 with many dating to before 1950. The majority of these aging digesters have long since corroded to the point that owners and/or users have resorted to weld buildup to restore wall thickness and stainless steel weld overlays for additional corrosion resistance. Yet, these costly repairs and overlays often do not meet life expectations. In addition, inspections and/or testing of digester weld overlay can be problematic and are often limited to visual examination. In this three part article we will discuss engineering evaluation, inspection and stainless steel overlay repair options for batch digesters.

Horizontally applied overlay is conventional for batch digesters. This GMAW vertical-down overlay has insufficient corrosion resistance due to excessive carbon steel dilution and low thickness.

Introduction

Most batch digesters used for Kraft pulping have been fabricated from carbon steel with ample corrosion allowance. After a few years of operation, the corrosion allowance becomes depleted and digesters may be weld overlaid with corrosion resistant alloy to obtain additional years of operation. Eventually, the corrosion-resistant overlay becomes depleted and additional repairs are required. Theoretically, the stainless steel overlay can be replaced indefinitely, providing unlimited life of the digester. However, in practice, the wear-life of batch digesters is limited to two or three overlays because of distortion and surface deterioration problems. There are several ways to evaluate the useful life of the carbon steel digester once the stainless steel overlay process has begun.

Types of Overlays

The reader is encouraged to consult

New Employees Join M&M Engineering

Spencer Rex joined the M&M Engineering Associates, Inc. Staff in the middle of this year as an entry-level engineer Before joining M&M Engineering, Spencer graduated in Metallurgical Engineering from the University of Utah in May of 2009.

Spencer's experience includes two years as a process engineer intern and chemistry lab technician for Rio Tinto, Inc. at the Kennecott Copper Mine in Utah, as well as at the Rio Tinto Borax Mine in California.

Spencer began working in the M&M Engineering Associates, Inc. Metallurgical Laboratory. He will soon transition into an engineering position at M&M Engineering.

Henry Kight joined the M&M Engineering Associates Staff in July of 2009 as a Metallurgical Laboratory Technician.

Henry has many years experience as an R&D Technician at Texas Instruments, as well as several other companies supporting the computer industry. His areas of expertise include airflow and thermal analysis, thermal modeling, plastic and sheet metal component design.

In addition, he has experience as a lab technician performing environmental tests including shock and vibration, acoustic evaluation, UL product safety conformance testing and FCC agency approval testing. Henry is also an experienced process control designer, having helped to design three computer factories located here in the USA, Prague Czech Republic and Sao Palo Brazil.

Mr. Kight has also been instrumental in designing factory quality process controls used in factories in mainland China. Henry enjoys camping with his wife Gerri at their land on the Pedernales River, as well as restoring vintage sports cars in his spare time.

TAPPI TIP 0402-03 *Guidelines for Corrosion Resistant Weld Overlays in Sulphate and Soda Digester Vessels*, for useful and detailed information for application of high quality weld overlays [1]. The TAPPI document covers types of corrosion resistant weld overlays used in both batch and continuous digesters. Although both stainless steel and nickel-base overlays have been used, most batch digesters today are overlaid with stainless steel. Laboratory testing and experience has shown that for stainless steel overlay welds, the deposited final layer may need a chromium content of 24% or greater to best resist batch digester corrosion [2]. Until about 1995, the usual consumable material for stainless steel weld overlay was Type ER309L wire. The as-applied composition of 309L consumable, which varies depending on the extent of dilution with the carbon steel substrate, has only about 16% to 22% chromium and 9% to 12% nickel. Type 312 stainless steel consumables will have as-applied chromium content above 24%.

Corrosion-resistant weld overlays are applied using manual, semi-automatic and automatic weld processes. Applicators of the automatic processes use either sub-arc welding (SAW) or gas metal arc welding (GMAW). The automatic process is useful for all digester inside surfaces except near the bottom outlet nozzle, around nozzles and part of the top dome. These areas are completed using manual welding processes—either shielded metal arc welding (SMAW) or the GMAW process. Very good quality weld overlays can be obtained using any of the above manual or automatic weld processes. Both single and twin-wire welding processes can be used. The chemistry of the first pass is necessarily lean due to carbon steel dilution, and the second pass achieves the required minimum chromium and nickel alloy content for the overlay.

Weld overlays using the GMAW process may be applied in either the horizontal or the vertical directions. However, experience has shown that the horizontal method of application to be more resistant to the aggressive batch digester environment.

Corrosion "Hot Spots" in the Digester

Corrosion in batch digesters occurs preferentially with the most deterioration occurring at splash locations where liquor is first introduced into the digester. The liquor flashes when first contacting the digester walls, producing a corrosion damage mechanism called "hot plate boiling" [3]. Corrosion will be most pronounced wherever the liquor contacts the hottest surface between cooks. Thus, when filling the digester through the top head, the upper wall regions experience the most corrosion. Another high corrosion area is the bottom cone—especially the region under the liquor inlet nozzle. The lower cone is exposed to high corrosion rates when hot liquor is introduced prior to the introduction of chips as in "liquor packing." Corrosion rates on carbon steel often exceed 2.5-mm/year (0.100-inches/year).

Stainless steel weld overlays in batch digesters can corrode at unacceptable rates in liquor splash areas also—especially if the overlay chromium content is low. Maximum corrosion rates of Type 309L stainless steel and Type 312 stainless steel overlays may exceed 0.7-mm/year and 0.5-mm/year, respectively, depending on the chromium content of the overlay, the aggressiveness of the liquor and location within the digester. Likewise, very low corrosion rates in overlays are experienced in areas not subject to direct liquor splash, such as the lower sidewalls. Comparing carbon steel and stainless steel life using the above corrosion rates, the most vulnerable areas of the digester (upper walls and lower cone) in carbon steel may experience up to 25-mm (1.0-inches) metal loss in ten years. Type 309L stainless steel overlay applied 3/16-inches thick may have a life as little as six years while the life of Type 312 stainless steel overlay may still be less than ten years.

References:

1. TAPPI TIP 0402-03, "Guidelines for Corrosion Resistant Weld Overlays in Sulphate and Soda Digester Vessels."
2. A. Wensley, "Corrosion of Carbon and Stainless Steels in Kraft Digesters," NACE Corrosion 2000 Conference, Paper No. 589, March 2000.
3. Welding Research Council, Inc., Bulletin 488, "Damage Mechanisms Affecting Fixed Equipment in the Pulp & Paper Industry," Par. 5.1.1.2, January 2004.

Seminars and Workshops Attended

Dave Daniels of M&M Engineering Associates, Inc. presented a paper on Innovative Lay-Up and Startup Methods at the EPRI International Conference on Cycle Chemistry in Fossil and Combined Cycle Plants in Boston, MA, June 30, 2009 through July 2, 2009.

Ron Lansing, P.E. of M&M Engineering, presented a course on Non-Destructive Examination at the HRSG Users Group Annual Meeting held at the Hyatt Regency Jacksonville Riverfront in Jacksonville, Florida, April 6-8, 2009.

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For technical information, please contact:

David Daniels
(512) 407-3761
david_daniels@mmengineering.com

Ron Munson
(512) 407-3762
ron_munson@mmengineering.com

Karen Fuentes
(512) 407-3778
karen_fuentes@mmengineering.com

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