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MAINTAINING HIGH ENERGY PIPING INTEGRITY WITH UNIT SPECIFIC STRATEGIC PLANNING

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ABSTRACT

High-energy piping systems are essential to the safe and cost-effective operation of power plants. The propensity for piping failures increases with the age of the systems involved. Prolonged operation, particularly at elevated temperatures, may result in metallurgical degradation which in-turn increases the potential for cracking and crack propagation until a final failure stage is reached by the component. As a result, power plant operators have become increasingly cognizant of the importance of condition assessment evaluations for high-energy piping systems.

Power plant operators are faced with specific challenges to maintain the integrity of their high energy piping systems including the reduction of onsite engineers, aging workforces, equipment, and the need to remain competitive in a challenging global energy market. Plant managers are routinely faced with the complex task of evaluating the current condition of their equipment, forecasting outage budgets and schedules, and performing risk assessments. Additionally, insurance companies are increasingly requiring inspection and maintenance records that are not always up-to-date or readily available.

The solution to strategically maintaining the integrity of high-energy piping systems involves taking a comprehensive approach to piping management utilizing unit specific operational training, advanced data management, strategic inspection, maintenance and replacement prioritization. Implementing this comprehensive approach has resulted in avoiding both catastrophic and leak type failures for plant managers that have adopted this strategy. Implementing a unit specific, targeted plan enables utility owners and operators to succeed in today's competitive market by increasing the unit's reliability and availability without sacrificing safety or environmental standards.

Thielsch Engineering, Inc. hosts over 30 years of advanced engineering experience and provides extensive services to more than 150 power plants each year. Our firm is also the creator and proprietary owners of the 4 SYTE System Strategies that is currently operating in more than 60 power plants throughout the U.S. and Canada. We are an employee-owned company with 425 partners who are dedicated to best practices and customer service is a priority. Thielsch has offices in Rhode Island, Ohio, Texas and Florida.

INTRODUCTION

High-energy piping systems are essential to the safe and cost-effective operation of a modern power plant. The propensity for piping and failures tends to increase with the age of the systems involved. Prolonged operation, particularly at elevated temperatures, may result in metallurgical degradation. Metallurgical degradation may increase the potential for cracking and crack propagation until a final failure stage is reached by the component. As a result, power plant operators have become increasingly cognizant of the importance of condition assessment evaluations for high-energy piping systems and boiler components.

Significant levels of metallurgical degradation should be detected for conservative determinations of the remaining useful life of a component or system. With this information, proper planning and budgeting or repair and replacement programs can be performed. By proper planning and the performance of engineering evaluations, excessively long plant outages or interruptions of scheduled operations can be minimized and in some cases avoided.

Some of the challenges in prolonging the integrity of high energy piping systems include reductions in plant engineering staff, an aging workforce and the need to remain competitive. Plant managers are routinely faced with the daunting task of determining the current condition of their equipment, forecasting outage budgets and schedules, planning replacement schedules, and performing risk assessments for their facilities. Furthermore, insurance companies are increasingly requiring inspection and maintenance records and new EPA Regulations have become a major issue within the industry.

The solutions to extending the life of high energy piping systems involve taking a comprehensive approach to piping management utilizing unit specific operational training, advanced data management, and strategic inspection, maintenance and replacement prioritization.

This manuscript will examine and illustrate the challenges and solutions to prolonging the

integrity of high energy piping systems through the utilization of a unit specific strategic management approach.

PROLONGING HEP INTEGRITY: UNIT SPECIFIC STRATEGY

Each facility has its own unique operational history and conditions. In order to prolong the integrity and ensure the safety of your critical piping systems it's imperative to consider your facility's unique conditions to develop a strategic plan. Many plant managers and engineers never get started with an integrity program because the task is so daunting. Breaking this process into a three step approach simplifies the task.

PROCESS STEP 1 - SYSTEM REVIEW KEY COMPONENTS

Age of the Unit

Facilities built in the 1960's and 70's experience damage related to the obvious number of hours of operation; however they were designed with heavier wall thickness. As a result, these units' tend to have longer life expectancies than some of the newer facilities. Facilities that were built in the 1980's pushed the limits with the "do more with less" approach. Piping was supplied with thinner walled spool pieces, conserving costs on construction, but ultimately reducing the service life of the critical components. Modern facilities are being constructed to adapt to the thermal cycling that has become a part of the energy culture of today and are experiencing earlier than expected failures. Many of these failures are the result of exotic materials that are being used which have not been in service long enough to know the true behavior of the material under the thermal and mechanical stresses of cycling a unit.

Design of the Unit

During the operation of a modern steam turbine, moisture in the turbine will cause erosion on the turbine blade. This results in high maintenance costs and loss of power production and thus a loss of revenues that usually is far greater than the maintenance costs.

Therefore, all modern fossil power plants use superheated steam, which is conveyed through the “Main Steam Piping” system, and many of the large utility plants use a second superheater (called a reheater) that reheats the steam after it has passed through a portion of the turbine. This is usually done on a utility boiler application after the initial superheated steam passes through the high-pressure section of a turbine. The lower-pressure steam from this section of the turbine returns to the boiler, where the steam temperature is increased, and then returns the turbine through the “Hot Reheat Piping” system.

Another operating system widely being utilized in the industry today is the combined cycle HRSG. HRSG’s are typically classified into one of two types defined by the orientation of the exhaust gas flow: horizontal or vertical. Most HRSG’s in North America are horizontal arrangements which feature natural circulation, typically consisting of multi-pressure steam systems – high-pressure (HP), intermediate-pressure (IP), and low-pressure (LP). Smaller units, such as peaking plants, may have a dual pressure system. Larger, triple pressure units often add a reheat system to further boost the overall cycle’s thermal efficiency. These new breeds of HRSG’s were designed to operate at substantially higher flue-gas temperatures and steam pressures utilizing advanced, and for the most part, untested, boiler steels. The end result of these advances have yielded higher combined cycle efficiencies, however they have also created higher thermal stresses, fatigue cracking, creep damage, and corrosion concerns, particularly as units designed for base load were forced into cycling duty. These problems can manifest themselves within a few short years of commissioning and cause expensive and time consuming repairs.

Prior to determining the prioritization of inspection of a high-energy piping system, every effort should be made to assemble all applicable information on that piping system.

This would include, but not necessarily be limited to:

- Design Code
- Design pressure and temperature
- Operating pressure and temperature
- Operating hours

- Operating mode, e.g., base-loaded or cyclic
- Number of unit starts and characterization of start type
- Number of operating hours at off-design conditions
- Any upset operating conditions that could affect piping system integrity (This could include safety valve operation, turbine trips, water hammer, etc.)
- Pipe spool drawings
- Isometric drawings
- As-built drawings
- Fitting drawings
- Weld detail drawings
- Hanger support detail drawings (If this data is not available, then field hanger support audits are necessary.)
- Valve weights
- Original pipe stress analysis required for design acceptance. (If this is not available, then turbine nozzle loads and boiler connections loads are necessary.)

Materials

The American Society of Mechanical Engineers (ASME) has approved certain steel materials for use as tubes in boilers designed according to the ASME Boiler and Pressure Vessel (B&PV) Code. Section I of the ASME B&PV Code specifies allowable materials in Paragraph PG-9. Understanding the materials specific to a unit and recognizing the inherent concerns of those materials (weldability, resistance to elevated temperatures and pressure, heat transfer ability) will enable facilities to be more progressive in their pursuit to preventing service related damage.

Hanger Supports

Hot and Cold condition walkdowns of the hanger supports in each system should be audited annually. This will ensure that the piping systems are supporting as predicted and intended by the designer. (The condition of the supports provides an accurate

barometer of the overall condition of the applicable high-energy piping system. This is supported by the fact that over 95% of the through wall failures reported in high-energy piping systems is related to applied bending stresses from external or off design conditions. Often times these stresses are the result of improperly designed or malfunctioning hanger supports.) Figure 1 below illustrates a typical hanger design and location.

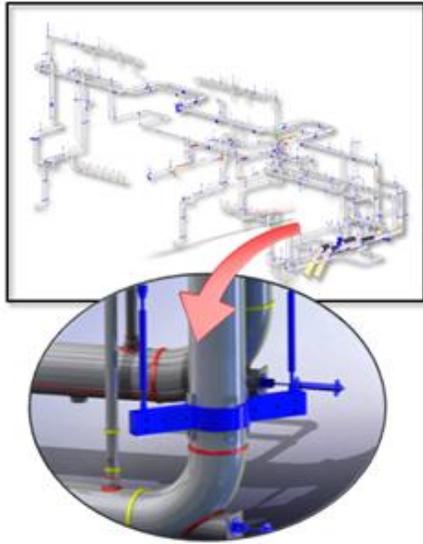


Figure 1. Typical hanger design and location.

Understanding P91

The use of modified 9Cr (grade 91) steel in modern power plants is derived from the superior properties of the material in comparison to carbon steels or lower chrome materials. It boasts superior creep and tensile strength characteristics, which allow thinner materials to be designed into piping systems, pressure vessels and tubing. These are enviable characteristics in terms of thermal cycling, hence the wide spread use of the material in newer combined cycle plants.

There are some critical drawbacks to this material that have been realized over its relatively short lifetime. It provides significant field welding challenges in terms of backing, preheat, and post weld, heat treat programs. There is little margin for error when welding and/or heat treating this material. Unlike carbon and low-alloy steels, the elevated creep

strength in 9-Cr material depends on achieving and maintaining a specific microstructure.

Any event during manufacture, erection, or operation that disrupts this microstructure will compromise the integrity of the material and prevent it from achieving the creep properties upon which the Code allowable stresses are based. In such cases the premature failure of such components is a reality. Additionally, softening of the material resulting in lower creep strength and can initiate type IV cracking of the material. It is paramount that the use of this material be firmly understood.

PROCESS STEP 2 - HISTORICAL REVIEW KEY COMPONENTS

Failure/Damage Locations

The ability to identify and track the locations of a piping damage or failure and its root cause is essential to comprehensively maintaining the safety and integrity of the high energy piping systems. Once the root cause of the failure/damage is properly identified, a long term plan can be implemented to ensure the failures/indications have been rectified. Proper and current documentation is critical to managing failures and indications and can be done in real-time with the use of a data management program such as the 4-SYTE System Strategy.

Failure/Damage Mechanisms

Although numerous conditions may cause or lead to service failures, the responsibility for a failure can generally be assigned to one of five classifications:

- Design (structural, design notches, joint location, or welding end configuration)
- Materials (selection and handling of base and welding materials)
- Base Metal Defects (introduced during manufacture and shaping of plate or piping components- pipe, cast valve, cast or forged fitting, etc.)
- Fabrication (fabrication, welding, heat treatment, or cleaning of pressure vessels or piping during shop fabrication or field erection)
- In Service (Fatigue, Creep, Thermal Shocking, Corrosion and Overload)

In some instances, the responsibility can be related to a combination of several of these classifications. For example, a pipe weld containing root defects, such as lack of penetration, may not fail during service until thermal or mechanical fatigue of sufficient magnitude initiates cracking and crack propagation of the existing defect through the cross sectional thickness. Figure 2 below illustrates a typical surface indication which required repair welding. The indication was discovered during a routine scheduled outage inspection.

A failure occurs by cracking or corrosion or



Figure 2.
Example of a surface indication discovered during a routine outage inspection.

sometimes a combination of both. The majority of failures occur gradually, in a ductile manner. They involve either a gradual propagation of cracks or corrosion across the wall thickness of a component. By bulging or leaking, ductile failures give warning to the operating personnel. It is fairly rare to experience a failure where partial cracking across the wall occurs, followed by a sudden pipe rupture, or where sudden rupture occurs which is not preceded by detectable prior cracking. These sudden rupture type failures are viewed with extreme concern as they may result in injury of personnel or loss of life, and many become extremely costly to the plant. Most of these failures are related to the brittle behavior of certain materials. Three conditions control this tendency for steel to behave in a brittle fashion. These include (1) high stress concentrations; (2) a high rate of straining;

and (3) environmental temperature. Although brittle failures are often considered the most catastrophic, it is important to recognize that cracking through ductile metal may also have considerable consequences.

Modifications

On occasion inherent deficiencies of a unit design will be identified. As a result, the unit may undergo design modifications which can resolve the original design flaw concerns, but ultimately can create other issues such as steam flow restrictions and temperature excursions etc. Additionally, as part of the clean air initiatives currently underway, many units are being modified to burn alternative fuels. Recognizing what modifications have transpired in a specific unit can lend perspective into potential side effects which may be occurring as a result of those modifications.

Replacements

As an aging plant begins to experience repeated failures, sections of piping will require replacement. These replaced sections will have fewer hours of operation; therefore will not need to be considered for inspection on the same schedule as original equipment within the unit. This observation is particularly unit specific and is a major basis for why a cookie-cutter approach to inspection/maintenance is ineffective and can lead to squandering of precious budget funding inspecting equipment that has not yet reached a point in its life cycle to require examination.

Operational Changes

Most power generation facilities were designed on the assumption that they would be operated in a base-load mode or infrequently cycled. However, in response to local power market conditions and the terms of their power purchase agreements, many plants are now cycling their units more frequently than designers had intended. This results in greater thermal stresses, more pressure cycles, and therefore more cyclic fatigue damage and overall faster wear and degradation to the critical components due to both the mechanical and corrosion

processes.

As a general comment, cycling service has an adverse effect on the life expectancy of a unit. This is due to the fact that cycling results in fatigue loading (alternating cyclic stresses); whereas base load operation results in creep (sustained stresses). Depending on the severity of the stresses, and the number of cycles, fatigue loading can result in cracking, particularly at restraint locations.

Upset Conditions

When a unit trips and is brought offline suddenly or experiences a water hammer event, an immense amount of thermal and mechanical fatigue can be introduced to the involved components. It is beneficial to understand if a unit has experienced any major upsets during its life cycle in order to determine if evaluating areas that wouldn't normally come under the microscope is necessary. This is similarly unit specific and would be comparable to the considerations you would evaluate if you were purchasing a used car. Just as the purchaser would investigate any past maintenance troubles or collisions of the vehicle prior to purchasing, plant managers must consider the history of their units prior to determining the inspection prioritization of their critical components.

If a high-energy piping system has been subject to an upset operating condition with the potential to affect the integrity of that piping system, consideration should be given to performing an inspection of the piping system as soon as practical after the event to evaluate the effects of the event. The following provides examples of upset operating conditions that may require further investigation.

For high-energy piping systems exposed to fires, the inspection should include visual examination of the lagging in an effort to identify possible exposure temperatures. In those areas where the piping system was exposed to temperatures in excess of the melting temperature of the lagging and was exposed to fire suppression activities, consideration should be given to performing replication and hardness testing. (Other nondestructive examinations may also be prudent.)

High-energy piping systems are subject to severe water hammer. The initial inspection after such an event should focus on the pipe supports in an effort to identify the actual movement of the piping system. This should be followed by nondestructive examination of the weldments in those areas that were subject to the greatest movement. If any event-related deterioration is identified, the scope of inspection should be expanded. Ultimately, this condition can be avoided by proper steam line draining programs and maintenance of the automatic drains.

A frequent occurrence observed by Thielsch Engineering is the collection of condensate in the lower horizontal sections of the Cold Reheat Piping system as a result of steam condensing during unit shutdown. This is typically the result of the automatic, low point drains not operating properly or they are clogged with scale and rust.

PROCESS STEP 3 - BUDGET REVIEW KEY COMPONENTS

Prioritization: Inspection, Repairs, Replacement

The ability (and necessity) to develop a plan of action that includes prioritization for inspection, repairs and/or replacements established from the unit specific design and historical operation will dramatically improve the budgetary process. Allotted funds will be used in an effective manner and outage planners will have the ability to provide "back-up" documentation required to warrant the necessity for such funding during the company fiscal budget planning process.

Primary Deterioration Mechanism

Steel materials normally are subject to changes in microstructures when the steels are exposed to temperatures above 800oF to 1000oF. The changes in microstructure tend to relate to the maximum temperatures reached, and the time at the respective temperatures. If the temperatures are sufficiently high and the stresses to which the header, steel pipe, welds, or tubes are subjected are of sufficient magnitude, dimensional changes may develop. Such dimensional changes at elevated temperatures are known as creep. Creep represents the permanent plastic deformation, which can occur at

elevated temperatures and at stresses significantly less than the yield strength of the steel at the same elevated temperatures. Creep at elevated temperatures normally is identified by a curve, which shows four portions; Figure 3. The first portion involves the initial extension (or expansion) at elevated temperature. This extension is partially elastic.

In the next stage, the extension (or expansion) rates decreases with time. This stage is also called a transient or primary creep stage. The primary creep stage is not considered to represent damage. Subsequently, a stage occurs on the creep

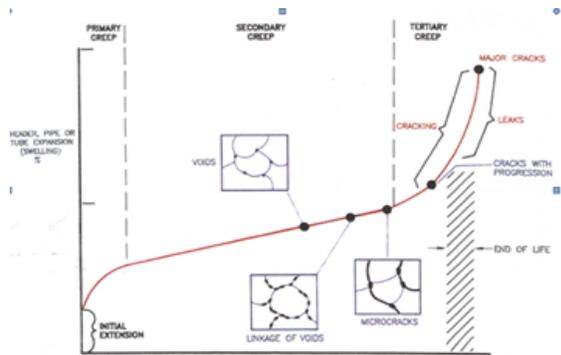


Figure 3. Stages of Creep Development. As creep stages progress, illustrated in the graphic above, the voids begin to link with one another, developing into cracks which then propagate through the material eventually causing leaks or failures.

curve located where the rate of creep (expansion) is nearly constant. This stage is also called secondary creep. The period of secondary creep after some expansion (i.e., in the latter period of the stage) is evidenced by initial void formation along the grain boundaries. In time, these tend to join or "link up". Void formation generally tends to develop after approximately 50% of the life of the pipe material has been consumed. Thus, on the basis of the microstructures and the absence of any evidence of void formation, the high-energy Piping would be expected to be suitable for another 200,000 hours of service.

The fourth stage of the creep curve, located beyond the constant creep rate portion, involves a rapidly increasing creep rate. This stage is called tertiary creep. It involves grain boundary fissuring (or microcracking). After this stage is reached, the material would tend to develop failure. This may represent a "remaining-life" period of 5% to 10% of

the prior operating period. Thus, when the header or pipe material reaches the tertiary creep stage, the end of the useful life of the steel material, at the specific area of high-stress levels, is being approached. In many components, the tertiary creep stage may not be reached until after 200,000 to 500,000 hours of operation, or longer. However, in other instances, particularly involving overheating of Superheater tubes, the tertiary creep stage has been reached after only 10,000 to 50,000 hours of operation. Such overheating, however, would generally involve temperatures of 1100oF to 1200oF. These are generally higher than the applicable design temperatures of most piping systems.

The results of stress rupture tests performed on samples removed from a high-energy piping system can provide information about the remaining useful life of a high-energy piping system.

To provide additional information regarding the condition of a high-energy piping system, the remnants of stress rupture samples are subject to metallographic examination. The observed microstructure will provide information about the condition of the piping system. Particular attention should be paid to the extent of carbide precipitation and agglomeration as well as creep determinations. i.e.: void formation and void linkage or microfissuring.

Outage Schedules

Facilities typically have an outage schedule to provide regularly scheduled maintenance and inspection of major components. Short outages typically occur once a year and last about 7-10 days. Major outages typically occur every two-three years and last in upwards of 3-6 weeks depending on if replacements are scheduled or major overhauls of equipment are required. Developing a firm plan of action and having a concrete understanding of when and why these outages are scheduled can help allocate funding for prioritization of inspections and maintenance.

For example, if a plant is experiencing a valve leak, but aren't scheduled for a major outage for another year, it may elect to do a "quick fix" or

“band aid” type of repair to continue operations until the major outage. It is paramount that the problem be properly analyzed to ensure that the temporary method to “hold” will be effective. This determination requires experience, expertise and documentation of the components in question. All of this can be obtained by utilizing a unit specific strategic plan with a custom data management program.

Budgetary Allocation

Alas, the budget. A common frustration among plant managers and planners occurs when the hurdles associated with identifying what needs done have been surpassed; yet retaining the appropriate funds becomes a challenge. Planners must justify the priority for the proposed funds and with that, clear documentation and professional support is essential.

Once the requested funds have been allocated, it must be utilized in the most effective manner with a clear plan of action. A unit specific plan and a real time management plan will not only maximize the return, but also improve overall safety and reliability. Budgets can be justified when the system review and historical data have been retained and readily available by way of a data management program.

EPA Regulations

EPA regulations change constantly and facilities are faced with having to upgrade emissions or retrofit to meet these EPA regulations. Funding that would have otherwise been used for maintenance and inspection or replacements are then reallocated. A comprehensive unit specific strategic plan combined with a data management program will assist in early detection of a unit’s remaining useful life cycle and/or identify solutions that could potentially void the need to decommission or upgrade. More and more facilities are being decommissioned rather than upgrading because the cost of performing the needed modifications outweigh the profitability of the unit’s potential output.

Safety and Risk Management

Safety and risk management are highly regulated and are vital to a facilities success. A comprehensive program that focusses on operator training, maintenance and testing, as well as replacing components that have reached the end of their useful life can reduce the risk of component failures within a power boiler. The need to create this custom plan is essential to the overall operation of the facility and most importantly the safety of the workers. Additionally, a progressive data management plan can offer extensive reductions in insurance costs as this establishes a proactive philosophy to prevent catastrophic events.

Run, Repair, Replace

The presence of cracks invariably leads to decisions about run, repair, or replacement. However, the presence of surface cracks in a thick-walled component may not mean steam leak is imminent and, in certain circumstances, operation with cracks may be acceptable. Assessments in such cases depend on accurate crack growth data and analytical procedures described earlier. In view of the uncertainties in operating conditions and the lack of crack growth data on service-exposed material, may utilities opt for defect repair at planned outages? Clearly such options can only be exercised if suitable weld repair procedures are available. Much research has been undertaken to improved weldment ductility by control of weld process variables to produce favorable microstructures or by modifications to weld metal composition.

As discussed, service experience often indicates that the first observable creep damage occurs as cracking at weldments. However, examination of weldments is not usually sufficient to ensure overall structural integrity. In many cases, welds can be successfully repaired without reducing the overall component life. When problems have been identified, alternative to replacement sometimes exist.

Furthermore, even when replacement is inevitable, remedial action to allow continued operation may be necessary. A list of potential actions for common problems in critical components includes control of temperature ramp rates to

minimize thermal stresses, maintenance of support to minimize system loading, and proper control of welding processes and subsequent post-weld heat treatments. Such a list cannot be considered as comprehensive, but in general, when problems with creep damage have been identified, significant improvements in service performance are invariably derived by reducing peak operating temperatures and/or the rate of temperature changes. The penalties to efficiency resulting from such action are usually severe so that mechanical modification or alternative material selections are normally required.

Taking the above unit specific considerations into account when developing a strategic high energy piping integrity program is essential to targeting the specific financial challenges a unit may be experiencing. Additionally, as the high energy piping systems reach the end of their useful life, replacements will need to be allocated for. Replacing entire piping systems is not a cost effective approach, and would be unachievable during a typical outage. Strategically planning for the replacement of specific spool pieces, utilizing an equipment management program, is a more comprehensive and cost effective approach.

CASE STUDIES

The following instances of piping damage and/or failures represent a small sampling of cases that Thielsch Engineering participated in the evaluation and subsequent repairs involving high energy piping systems in the Utility industry. These cases illustrate several types of damage that can develop as a result of the harsh environments these systems are exposed to during their service life.

Mechanical Fatigue

In April of 2010, Thielsch Engineering discovered two significant indications in the girth welds located on the legs of a wye block in the Main Steam piping system of a power station located in the Midwest.

The linear fatigue-type surface indications were discovered during the wet fluorescent magnetic particle examination. The first indication was 13"

long, at the 12:00 o'clock in the toe of the weld on the north wye block. The second indication was 4" long at the 12:00 o'clock position, in the toe of the weld on the same wye block. These indications were evaluated and confirmed to require repairs. Figure 4 below illustrates the indication location and repair.



Figure 4. Images of the indication which required weld repair.

The boiler of this facility is a radiant reheat boiler that was designed and erected by Babcock and Wilcox. The design and erection of this boiler would have been carried out in accordance with the requirements of Section I of the ASME Boiler and Pressure Vessel Code. (This Section of the Code covers "Power Boilers".) The boiler is rated to deliver 4,545,000 pounds of steam per hour and was placed into service in 1981. Since that time, it had been operated in a base-loaded manner. At the time of the evaluation, the unit had accumulated 211,875 hours of operation.

The high-energy piping systems would have been designed and erected in accordance with the requirements of the ASME B31.1 Code on Pressure Piping covering "Power Piping." The Main Steam piping system was reportedly fabricated using pipe manufactured in accordance with the requirements of ASTM Specification A-335, Grade P22.

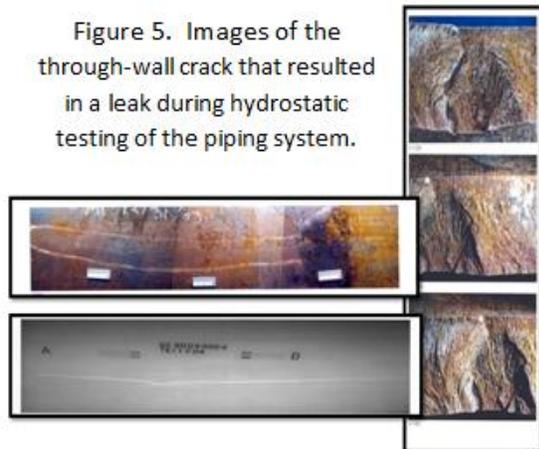
Thielsch Engineering was contracted to provide guidance and supervision to supply a weld repair program, and to perform repairs by welding on the Main Steam piping system, thus returning the piping to a level of integrity suitable for continued service under design operating conditions. After conducting a thorough examination of the piping

system, it was revealed that several hangers upstream and downstream of this weld were either damaged or bottomed out resulting in insufficient piping support and movement. A full hot and cold condition hanger walkdown and pipe stress analyses were recommended to bring the unit back to a suitable condition for continued safe and reliable operation.

P91 Piping Failure

In January of 2004, General Electric Power Systems (GE) submitted a pipe segment to Thielsch Engineering. This pipe segment had been removed from a Hot Reheat piping system from a facility in Pennsylvania. It contained a through-wall crack that resulted in a leak during hydrostatic testing of the piping system. Thielsch Engineering was requested to perform a detailed metallurgical evaluation of the pipe segment to determine the cause of the crack.

The design, fabrication and erection of the Hot Reheat piping system were reported to have been performed in accordance with the requirements of the ASME B31.1 Code on Pressure Piping covering "Power Piping". The design of this piping system was completed by Sargent & Lundy of Chicago, Illinois. The design conditions involved a pressure of 650 psig at a temperature of 1050°F. Sargent & Lundy elected to use alloy steel pipe and fittings. The pipe was produced in accordance with the requirements of ASTM Specification A-335, Grade P91 covering "Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service". (For reference purposes, Grade P91 is a modified 9 Cr - 1 Mo alloy steel material.) Figure 5 below displays images of the through-wall crack in the P91 material.



The results of the metallurgical evaluation confirmed that the pipe segment had been subject to localized overheating. The localized overheating was sufficiently severe to result in re-austenitization, grain growth and cracking. The cracking and microstructural transformations introduced during the localized overheating rendered the pipe subject to brittle failure during subsequent handling.

The defect present in this pipe segment represents a localized condition. On the opposite side of the pipe segment, the microstructure and tensile properties were typical for pipe produced in accordance with ASTM Specification A-335, Grade P91. The source of the localized overheating could not be identified definitively from the results of the metallurgical evaluation. It is known, however, that the overheating occurred prior to the radiographic examination and postweld heat treatment of the affected field weld. Possible sources of localized overheating include the tempering heat treatment performed during original manufacture of the pipe, postweld heat treatment performed during fabrication of the spool piece of which this pipe was part, or some undocumented event.

Fatigue-Creep Piping Failure

In May of 2002, a leak occurred in a Main Steam piping system at a facility located in the Midwest. This leak was the result of through-wall cracking that developed in the intrados of a clamshell elbow. Thielsch Engineering performed a metallurgical evaluation of two boat samples removed from this elbow to determine the cause of the cracking. The results of this metallurgical evaluation confirmed that the cracking in these boat samples was caused by fatigue acting in conjunction with creep. The cracking is the result of an applied bending stress. (The condition of the elbow, which had been welded with a low carbon filler material, contained at least one original weld defect, and had been heavily ground subsequent to welding, rendered it susceptible to failure by fatigue and/or creep.)

This piping system was designed and erected in accordance with the requirements of the ANSI (now ASME) 831.1 Code on Pressure Piping

covering "Power Piping". The Main Steam piping system was designed to withstand a pressure of 2,650 psig at a temperature of 1015°F. (The operating conditions for this piping system involve a pressure of 2,400 psig at a temperature of 1000°F.)

The Main Steam piping system was erected using low-alloy steel pipe and fittings. The pipe was produced to the requirements of ASTM Specification A-335 covering "Seamless Ferritic Alloy Steel Pipe for High-Temperature Service". It involved Grade P22, a low-alloy steel material with a nominal composition of 2-1/4% chromium and 1% molybdenum, i.e., a 2-1/4 Cr- 1 Mo low-alloy steel. The fittings were produced to the requirements of ASTM Specification A-217, Grade WC9 covering "Alloy Steel Castings for Pressure-Containing Parts Suitable for High-Temperature Service". Figure 6 illustrates the through-wall crack and repair process.



Figure 6. Images of the through-wall crack which required weld repair.

Thielsch Engineering developed and instituted a repair welding program to address the

cracking that had developed in the intrados of the elbow. This program, which complied with the requirements of all applicable Codes, has restored the replacement elbow to a level of integrity suitable for continued service for at least five additional years.

CONCLUSIONS

Modern and Proven Solutions

Thielsch Engineering, Inc. has spent the past 30 years working with America's power producers and advanced manufacturers to ensure safety, reliability and profitability. Every producing facility must have a system in order to better manage overall operations and the use of a data management plan such as our proprietary program 4-SYTE System Strategy offers control and real-time solutions from anywhere in the world. The combined process of integrated engineering that includes unit specific education, observation, tracking, proper maintenance and data collection provides a modern approach to a complex and highly competitive market.