Using Linear Phased Array Ultrasonics to Inspect New Boiler Tube Welds

As fossil boilers age, waterwall and tubing sections that have expended their useful life for various reasons are routinely replaced to avoid unplanned outages resulting from tube leaks. For years, SI has been the industry leader in detecting and evaluating conditions that could lead to forced outages. Now we are using our advanced ultrasonics to inspect replacement tubing installation welds to ensure that the new welds are sound and will provide good service.

Traditionally, utilities have used radiography (RT) as the nondestructive inspection method to determine weld quality. However, owing to the hazards associated with radiation exposure, workers must be cleared from a relatively large work area for the duration of the RT inspection, halting useful work in that area. One utility calculated that these necessary safety requirements reduce the amount of available production welding by 2 to 4 days per major (six week) overhaul.

Linear Phased Array (LPA), an advanced form of ultrasonic inspection, offered several advantages over RT for the overhauls. First, unlike RT, no work stoppage or relocation of the welders would be required as no safety hazards exist with the inspection technique. Second, a larger number of welds could be inspected because of the higher inspection productivity as compared to RT. Third, unlike RT, LPA is well suited for the detection of planar, crack-like indications such as lack of fusion, which are more likely to result in premature failure.

To allow implementation of LPA in lieu of RT, SI developed and refined the inspection protocol, developed acceptable and unacceptable flaw sizes based on analysis, fabricated performance demonstration standards containing flaws in tubes of the thickness and diameter of the tubes to be examined, and finally, benchmarked the LPA inspection results against RT.

The benchmarking effort, essential for acceptance of the new method, included the performance demonstration standards, radiographically rejected welds from another overhaul, and several welds that were accepted by radiography, and contained acceptable indications. Finally, during the first week of the first overhaul, both RT and LPA were used to examine the same welds. In all instances, equivalent results were found.

LPA was then used as the primary inspection technique for boiler tube pressure welds made during two major spring 2006 overhauls. The higher productivity of LPA allowed inspection of a higher percentage of field welds, increasing the chances of finding welds that would force the plant offline. While typical RT examinations include only 10% of fabricated welds, about 20% of the over 4,000 welds were inspected during the first overhaul, with each UT inspector averaging over 40 welds per day. During the second overhaul, the sampling rate increased to about one third of all welds.

For additional information, please contact Harold Queen at (954) 572-2902 or hqueen@structint.com, or John Arnold at (860) 536-3982 or jarnold@structint.com.
President’s Corner by Laney Bisbee

This summer SI celebrated its 23rd year and many successes with an all employee meeting. During the meeting we were privileged to hear reflections from one of our founders (and SI’s President for the first 21 years), Pete Riccardella. Pete succinctly captured much of SI’s history through the review of a list of technological firsts achieved by SI. Pete’s message was clear - one critical component of SI’s success has been innovation.

I recalled Pete’s message during a recent client meeting where we discussed the innovations being applied to their pressurizer nozzle weld overlay project. Through the W(SI)² team, this one project included no less than eight significant innovations, including new overlay welding equipment, remote machining, and the first use of a PDI-qualified linear phased array ultrasonic inspection. This experience prompted me to then research the answer to the question, ‘Is SI sustaining its credo of innovation?’

My survey revealed the following recent, important innovations:

- Long Range Guided Wave (G-Scan™) inspection with integral allowable wall thinning evaluations for nuclear, fossil, and pipeline applications.
- First ever PDI qualification and field implementation of Linear Phased Array UT for weld overlays of critical nuclear piping.
- Linear Phased Array UT in lieu of RT for the butt weld acceptance testing of replacement waterwall tubing.
- Sound welding processes for Alloy 52M weld overlay repairs and half-nozzle repairs of critical nuclear piping.
- Integration of weld overlay design with Linear Phased Array inspection to minimize weld overlay length and to maximize inspectable volume.
- Portable handheld dynamic data acquisition systems (SI-MiniDAS™)
- Minimum 16-bit resolution for all currently offered vibration-related data acquisition devices.
- Universal automated vibration-related data processing software to reduce analysis time.
- Linear Phased Array inspection of fossil header stub tube socket welds to reduce inspection time and provide through wall crack dimensions.
- In-situ high-resolution NDE technique, in conjunction with stress and fracture mechanics analyses, to help utilities assess the potential for generator shaft keyway cracking without costly disassembly.
- Macro to speed up and greatly simplify the process of inserting crack tip elements in finite element models, optimizing the modeling of flaws in 3-D structures.

Obviously we are continuing and even accelerating our rate of innovation. You’ll find articles expanding on several of these recent SI innovations in this issue of News and Views.

Root Cause Evaluation of RHR Bypass Line Cracking

In December of 2005, a Reactor Coolant System (RCS) pressure boundary leak forced Plant Vogtle Unit 2 into an unscheduled outage. The leak was in a 3/4-inch socket weld between a flow restrictor and a half-coupling on the bypass line for a Residual Heat Removal (RHR) suction valve. Poor weld quality was determined to be the most probable cause of the leak. However, leaks at two other welds in the same bypass line in February 2006 led to a metallurgical analysis, which showed that some sort of fatigue mechanism was responsible for these cracks. A March 2006 leak, at the same weld location as the December 2005 leak, underscored the need for a thorough investigation of possible degradation mechanisms.

Possible failure mechanisms fall into several categories: thermal fatigue, stress corrosion cracking (SCC), localized corrosion (LC), flow-sensitive (FS) mechanisms, mechanical/vibration fatigue, creep, plastic deformation, and fabrication-related mechanisms. A failure analysis report prepared by the client found no evidence of SCC or LC. FS, creep, and plastic deformation mechanisms were also quickly eliminated. SI performed the following analyses to narrow things down further:

- Piping analyses of cold springing, thermal expansion, and support binding eliminated these as possible causes.

(Continued on page 4)

Charlotte, NC Office Expansion

Planned for NPS

Bud Auvil has been named to head SI’s new Nuclear Power Services (NPS) office planned for Charlotte, North Carolina. Select relocation of technical and project management personnel, currently working in NPS’ San Jose, California and Denver, Colorado offices, are expected to happen during 2007 in support of this expansion. External hires are also planned. This move is being undertaken in an effort to improve SI’s responsiveness to a nuclear utility market that is predominantly eastern-US based.

SI’s nuclear and fossil NDE manpower and equipment are currently housed in a 10,000 square foot facility in Charlotte near EPRI’s NDE Center. Plans for expanding SI’s existing Charlotte facility, to support growth of both SI’s NDE and NPS resource base, are being developed.

Candidates interested in employment opportunities with SI in Charlotte or elsewhere should visit http://www.structint.com/careers.html.
The team of Welding Services Inc. (WSI) and Structural Integrity Associates, Inc. (SI), in conjunction with two different utility clients, have recently completed four planned pressurizer refurbishment projects, which included a total of 22 weld overlay repairs. Overall, there were no recordable UT indications.

These projects introduced the following innovations for weld overlay repairs:

- Sound welding process – Welding schedules were developed and validated that are tolerant to a broad range of field conditions.
- Fiber optic controls – Welding was controlled from a distance of nearly one mile (>4,500 feet) from the reactor building due to workspace constraints and in an effort to minimize dose.
- New overlay welding equipment – WSI employed its new dual-torch ‘Omega’ weld head (patent pending), that facilitates effective use of ‘double-up’ weld progressions for out-of-position Alloy 52M welding. The dual-torch design eliminates schedule impacts for machine cable rewrap. Coupled with the new weld heads are the latest GoldTrac VITM power supplies and WSI-designed state-of-the-art digital operator video control consoles.
- New remote machining - Surfaces were prepared for NDE remotely using WSI’s proprietary LPA UT.
- New remote welding - WSI has also been able to make connections and weld from the surface of the piping, without the need for welding access.

WSI’s LPA UT technique incorporates the use of a separate probe and its associated wedges. Should as-built conditions require, machining of only the wedge is required for LPA UT examination. This machining scope can easily be accommodated on-site and generally within one hour of the identified need.

For more information, please contact Michael Lashley at (303) 792-0077 or mlashley@structint.com. 

SI successfully qualified and has now repeatedly applied a first-of-a-kind Linear Phased Array (LPA) UT inspection in the field for Alloy 600 weld overlay repairs. Qualification of the process and, in turn, SI inspection personnel was completed in September 2006 via the EPRI Performance Demonstration Initiative (PDI) process. Since completion of the PDI qualification process, LPA UT examination has been completed for 22 different weld overlay repairs at four different nuclear sites. All weld overlay repairs examined were completed by Welding Services Inc. (WSI), with the result of no recordable indications.

Use of SI’s proprietary LPA UT technology for weld overlay inspections offers the following distinct advantages over conventional UT examination:

- Examination Schedule/ALARA – Conventional UT examination of weld overlay repairs can require as many as 13 or more scans to provide complete coverage. However, LPA UT can cover a wide range of angles with a single scan, thus reducing the required number of scans to four (two axial and two circumferential). This greatly reduces scan time, improving schedule and decreasing radiation dose for examiners. For example, typical scan time for a pressurizer surge line weld overlay repair has now been reduced from a 12-hour shift for a crew of three to approximately 2 hours for one examiner with the use of LPA UT.
- Risk Reduction – Typically, probe sets for conventional UT examinations of weld overlay repairs are ordered based on overlay design and in advance of the need (due to a 10 to 12 week delivery time). The risk of improper fit and, thus, a significant change in probe requirements, as a result of variances in the as-built repair, is substantial and can lead to significant repair schedule delays and expediting costs. SI’s LPA UT technique incorporates the use of a separate probe and its associated wedges. Should as-built conditions require, machining of only the wedge is required for LPA UT examination. This machining scope can generally be accommodated on-site and generally within one hour of the identified need.

In addition to the above, LPA UT offers advantages in coverage volume, potentially reducing the length of weld overlay repair designs, thus reducing welder exposure.

For more information, please contact Bud Auvil at (704) 458-8883 or bauvil@structint.com.
Root Cause...

- SI determined acoustic resonance and vortex shedding frequencies, identifying the possibility of amplification of vortex shedding frequencies near 30 and 170 Hz.
- Evaluation of thermal stratification per EPRI/MRP guidelines showed stable stratification outboard of the isolation valve, but no stratification cycling.
- Vibration analysis showed that, during plant heatup, vibration stresses peaked at about 80% power, when the acoustic and vortex shedding frequencies are in alignment. While significant, the vibration stresses did not exceed the material endurance limit.

Additional vibration data collected after plant restart showed an unusual shock or “pulse” loading. Comparison with plant logs indicated that a valve had been opened on a connecting safety injection line to rapidly drop the pressure in that line and thus reseat a leaking check valve. It is believed that the rapid pressure drop caused the liquid in the line to flash to steam, and the ensuing void collapse sent a pressure wave up the line, which then caused the RHR bypass check valve disk to chatter. The vibration following this pulse loading was sufficient to exceed the endurance limit and fail the socket weld.

SI recommended changes in operation and plant configuration to prevent recurrence. Key among these were:

- Eliminate the check valve reseating procedure.
- Replace the swing type check with a lift or tilting disk check.
- Ensure that socket welds are as free of defects as possible.
- Use a 2x1 leg length geometry, using ASME Code Case N-666 if building up an existing weld.

SI also performed vibration and crack growth analyses on the Unit 1 bypass geometry, and showed that similar failure was unlikely for Unit 1.

For more information, please contact Paul Hirschberg at (408) 978-8200 or phirschberg@structint.com.
SI Associate Chairs “Corrosion in the Nuclear Power Industry” for ASM

Due to his worldwide renown in the area of corrosion in nuclear power plants and his previous authorship with the American Society for Metals (ASM), SI’s Barry Gordon was asked to lead ASM’s update of the chapter on corrosion in the nuclear power industry for Volume 13c of their popular metals handbook series. Aside from originally writing the introductory section and co-authoring “Corrosion in Boiling Water Reactors,” Barry assembled the world’s nuclear power corrosion experts to write the other sections of the chapter, including “Corrosion in Pressurized Water Reactors,” “Effect of Irradiation on Stress Corrosion Cracking and Corrosion in Light Water Reactors,” “Corrosion of Zirconium Alloy Components in Light Water Reactors,” and “Corrosion of Containment Materials for Radioactive Waste Isolation.” Details for Volume 13c can be viewed at www.asminternational.org/volume13c.

Much of the updated information was based on Barry’s SI training class “Corrosion and Corrosion Control in LWRs.” Please check out www.structint.com.

For more information, please contact Barry Gordon at (408) 978-8200 or bgordon@structint.com.

Assessment of ASME Code Temperbead Weld Procedure Qualification

Note: This article is adapted from “Assessment of ASME Code Temperbead Weld Procedure Qualification”, Co-authors R. Smith and A. McGehee, EPRI 7th International Conference on Welding and Repair Technology for Power Plants, Marriott Sawgrass Conference Center, Jacksonville, FL, June 2006.

The overall goal in qualifying temperbead weld procedures without post weld heat treatment (PWHT) is to ensure that the welding process will not degrade the mechanical response of the material being welded, when compared to the original condition that received PWHT. Toughness properties are the key to the qualification.

ASME Boiler and Pressure Vessel Code testing protocol requires measurement of a reference nil ductility temperature (RTNDT) that is used to index low alloy steels to a reference toughness curve provided by the Code. This curve prescribes the rate of toughness increase with temperature, and the reference temperature identifies the temperature range over which this upswing in toughness occurs. The testing protocol determines a nil ductility temperature (NDT) using the standard drop weight test. Then, at a temperature 60°F higher than the NDT, three Charpy-V (Cv) impact samples are tested that must meet a minimum requirement of 35 mils lateral expansion. If the minimum requirements are met then the NDT becomes the RTNDT. If not, then additional sets of three Cv samples are tested at increasing temperatures until the minimum requirements are met. Subsequently an RT is defined 60°F below the temperature where the minimum requirements are met.

Any increase in the RTNDT for the weld repair process is undesirable, because it will necessarily increase the lowest temperature at which the component can be pressurized. This has not been a problem for temperbead testing where the test material is similar to the original material of fabrication. Temperbead welding typically produces a weld heat affected zone (HAZ) that is mechanically superior to the original base material as measured by the Code test protocol. The problem is that the modern materials are so tough in relation to where the drop weight NDT is measured that the improved toughness of the HAZ is difficult to demonstrate.

SI conducted a study for EPRI that considered testing differences to be expected with different vintage materials when using testing protocol required by Code. Test results from a current heat were compared to results obtained historically. The results suggest the Cv test temperatures for modern materials prescribed by the drop weight test are too far up the transition range to demonstrate improvement in HAZ properties.

A better approach is to develop the full Cv curves using single tests at many temperatures for both the HAZ and base metal, then compare the transition shift at 50% shear. A negative shift would define an effective welding procedure. The figure at the left displays this procedure for modern low alloy steel, showing the huge improvement in toughness for the HAZ. These results suggest that alternate toughness testing criteria be considered for temperbead welding procedure qualifications to obtain an accurate evaluation. The full report is published by EPRI as RRAAC Report No. 1013553, Acceptable Cv Results for Temperbead Weld Procedure Qualification.

For more information, please contact Dick Smith at (704) 677-2370 or rsmith@structint.com.
**New People at SI**

**Benjamin Owen** is a graduate of the Southeastern Community College’s NDE program and is one of SI’s newest ultrasonic practitioners, helping deliver linear phased array solutions for the fossil NDE Services group.

**Mark Jaeger** has joined our Denver, CO office. Mark has recently received his BS in Mechanical Engineering from South Dakota School of Mines and Technology.

Newly hired in our San Jose office, **Eric Houston** has a Bachelor’s degree from University of Texas in Mechanical Engineering. Prior to joining SI, Eric worked on the structural design of sonar test equipment. He is now working in the areas of wall thinning evaluation, FatiguePro, and fracture mechanics.

**Jason Krupicka** is an Integrity Engineering Analyst for SI Pipeline Services in our Denver office.

**Terry Herrmann**, a Syracuse University graduate, has 30 years of experience in nuclear design, construction, testing, failure analysis and PRA, including extensive experience in the Maintenance Rule, surveillance testing and preventive maintenance. Terry works in our Denver office.

**Diep Nguyen** joins our Accounting staff in San Jose as an Accounts Payable Specialist. Diep has over 12 years of accounts payable experience and will be helping streamline our process.

**Shane Cavanaugh** has joined our Stonington, CT office. He recently graduated from Maine Maritime Academy with a BS degree in Power Engineering Technology.

**Ping Wang**, who has joined our San Jose office, is an expert in finite element analysis, and is published in the areas of fracture mechanics and mechanics of materials. He has a Masters degree in Civil Engineering from Vanderbilt University, and and has degrees from Beijing University in both Aeronautics and Solid Mechanics.

**Amanda Seeliger** has joined the staff of our Materials Science Center in Austin. She graduated from The University of Texas with a BS degree in mechanical engineering in May 2006.

**Sean Hastings** has rejoined SI after an 8 year hiatus, and now works on advanced eddy current and ultrasonic inspection applications development in our Charlotte office. Sean is a mechanical engineering graduate of the University of North Carolina at Charlotte.

**Steve Jeffery** has joined SI in the position of Executive Human Resources Director in our San Jose office. Steve has over 25 years as an HR professional with leadership experience in all aspects of HR, including recruiting, staff and organizational development, and performance management.

**Nancy Nicolaysen** is a Technical Typist in our San Jose office. Nancy comes to us with over 15 years of Administrative Experience.

**Jeff Henry** is an internationally recognized leader in advanced materials, metallurgical analysis, and evaluation of critical components for conventional, co-generation, and advanced design fossil power plants.

**Dan Peters** works out of SI’s Uniontown, OH office, and has extensive experience in the design, analysis and in-service inspection of ultra-high pressure (up to 150,000 psi) vessels and systems.

**Terry Haigler** is a Laboratory Assistant in the Charlotte office, helping with NDE development and with field services (when school doesn’t interfere). He is attending college and expects to receive his BS in welding engineering in August 2007.

**Ron Thompson** is responsible for troubleshooting and repair of some of SI’s advanced NDE systems, as well as providing field support for electronic repairs during nuclear NDE field projects. He has over 17 years experience in maintenance and repair of automated ultrasonic equipment.
New People at SI continued

Cliff Anderson brings an extensive background and knowledge of the energy business sector, including over 20 years of quality assurance/quality control and non-destructive testing responsibilities at nuclear, fossil fuel power stations, as well as activities for the aerospace industry.

Dr. Marshal Clark is helping SI establish a litigation business unit, leveraging his extensive experience in expert witness support for the electric utilities and SI's expansive expertise in all disciplines of engineering and nondestructive examination. Marshal is also an industry leader in the asset management of critical fossil plant components.

Chris Lohse has joined SI's technical staff in San Jose. UC Davis’ Mechanical Engineering Program provided Mr. Lohse with laboratory and analytical experience in dynamics, x-ray diffraction, fracture mechanics, thermodynamics, strength of materials, and control systems.

Gary Hensley is responsible for operations management the NDE Services Group and the Charlotte office. Gary brings an extensive background and knowledge of the combustion turbine industry, and will be working closely with the SI Fossil Plant Services leadership team over the next few months to determine this market’s potential for SI.

Robert Briley has joined SI’s nuclear NDE Services group as a Senior NDE Specialist in our Charlotte office. Bob has over 15 years of Non Destructive Examination implementation and supervision experience in the nuclear and fossil industries, both in the U.S. and abroad.

Ned Finney is supporting the growing needs of our nuclear NDE group in our Charlotte office. Ned brings extensive background in and knowledge of the nuclear industry, including project coordination and vendor surveillance for fabrication and inspection of nuclear quality components and piping.

Kewaunee Feedwater Piping Inspection and Analysis

At Dominion’s Kewaunee Nuclear Power Plant, utility personnel wanted to inspect a section of feedwater piping for flow accelerated corrosion (FAC). The challenge was that a portion of the piping is surrounded by an impingement barrier. SI used both G-Scan™ inspection and analysis to show that the piping had adequate thickness, saving the utility the cost of replacing the piping and reducing associated outage time impacts.

G-Scan™ uses low frequency, ultrasonic longitudinal and torsional waves (sending and receiving) to examine the piping. Depending on piping configuration and conditions, piping can be examined 100 feet or more in either direction from where the G-Scan™ collar is mounted on the piping. At Kewaunee, the G-Scan™ found wall loss within mill tolerance slightly downstream of the straight pipe to elbow weld for each of two elbows.

To determine whether the measured thinning was acceptable, SI determined minimum wall thickness in accordance with the code of construction (B31.1) and ASME Code Case N-597-1. Projecting the observed thinning forward in time, using conservative assumptions for initial wall thickness and thinning rate, the thickness was shown to be acceptable for at least nine more years of operation based on the original code of construction. However, using the higher allowable stress permitted in recent ASME Code editions, the piping was found acceptable for the remaining life of the plant.

For more information, please contact Ken Rach at (630) 728-2094 or krach@structint.com.
SI Senior Consulting Engineer Bill Amend volunteers at The Air Museum Planes of Fame (www.planesoffame.org) aviation museum in Chino, CA. Recently, he had a chance to put his metallurgical and failure analysis expertise to work for the museum. The museum’s one of a kind 1940s vintage Northrop N9MB Flying Wing developmental prototype had a partial engine failure and fire while being used to make an IMAX film. Through-wall fatigue cracks were found in the aluminum cylinder head where it mated with a cast iron combustion cylinder liner. Bill, together with a team of volunteers, concluded that the likely cause of failure was thermal stress cycling due to: (1) uneven temperature distributions across the head; and (2) thermal expansion mismatch between the aluminum and cast iron components. Museum staff are working with an aerospace casting house on selection of an alternate alloy to repair the engine and prevent future similar failures.

For more information, please contact Bill Amend at (562) 413-3190 or bamend@structint.com.