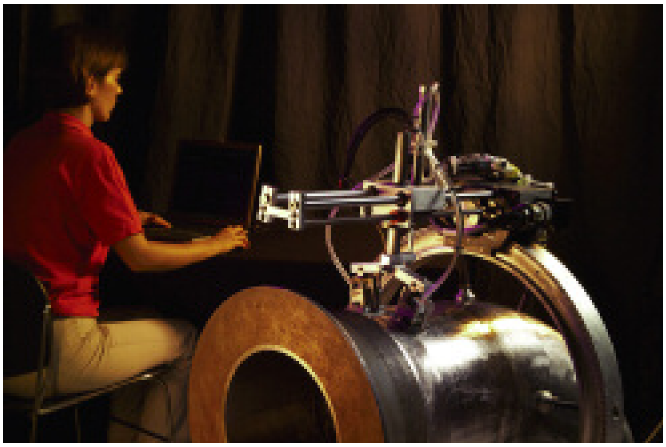
Nuclear Power Industry Strives to Achieve Updated UT Requirements

Qualifying UT procedures for examining nozzle to safe-end dissimilar metal welds according to the requirements of ASME Section XI, Appendix VIII, Supplement 14, has proved challenging

BY JOHN T. LINDBERG

The nuclear NDE services industry has been significantly challenged with the implementation of the ASME *Boiler and Pressure Vessel Code,* Section XI, Appendix VIII ultrasonic examination (UT) performance demonstration requirements. Initial examination qualification efforts by NDE services vendors often resulted in marginal success and limited qualifications. Considerable technical and economic resources continue to be expended in conducting these UT performance demonstrations.

Recently, Framatome ANP successfully completed a critical ultrasonic examination qualification to support the nuclear power industry. The UT examination qualification was required to be performed in accordance with the Performance Demonstration Initiative (PDI) program. The examination procedure addressed automated UT of dissimilar metal weld nozzle to safe-end in a pressurized water reactor, from the vessel inside surface (known as Supplement 14). This examination technique complements automated ultrasonic examinations performed on reactor pressure vessel welds and associated reactor vessel nozzle to safe-end welds in a pressurized water reactor (PWR). Figure 1 shows the typical configuration of a PWR outlet nozzle with shop welded safe-end. The aim of this article is to provide an introspective on the challenges associated with complying with ASME Section XI, Appendix VIII, and similar UT performance demonstration requirements.



A UT operator examines a nuclear reactor vessel nozzle-to-elbow weld qualification mockup. The equipment being used is an automated UT pipe scanner with ultrasonic transducers on the outside of the nozzle.

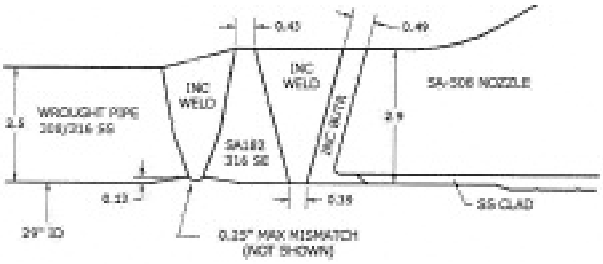


Fig. 1 — Outlet shop weld configuration.

Background

Within the U.S. nuclear industry, periodic nondestructive examinations of reactor pressure vessels and related pressure boundary components are required to assess their structural integrity. These examinations are required to be performed in accordance with the requirements of ASME Section XI, "Inservice Inspection of Nuclear Power Plant Components." Within ASME Section XI, Appendix VIII, "Performance Demonstration for Ultrasonic Examination Systems," provides detailed requirements for qualifying ultrasonic examination techniques, equipment, and personnel.

The Nuclear Regulatory Commission (NRC) has mandated the requirements of ASME Section XI, Appendix VIII, for ultrasonic examinations performed within the scope of ASME Section XI. These requirements have changed the quality and implementation of ultrasonic examinations in the U.S. nuclear industry. Compliance with the Appendix VIII requirements has resulted in improvements in the quality, technology, and reliability of ultrasonic examinations. However, industry's recognition of these improvements has been gradual because of the technical and economic challenges associated with the performance demonstration process.

In recognition of the challenges involved in complying with the Appendix VIII requirements, U.S. utilities formed the Performance Demonstration Initiative (PDI) to establish a unified approach for meeting these new requirements. Through cooperative funding from utilities and appointment of the Electric Power Research Institute (EPRI) NDE Center as the PDI administrator (known as the PDA), a program was established to conduct per-

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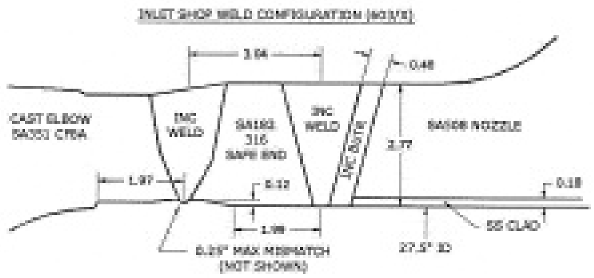

Fig. 2 — Inlet shop weld configuration.

Fig. 3 — Inlet field weld configuration.

formance demonstrations of ultrasonic examination systems. The key elements of the PDI program consisted of design and acquisition of open and blind ultrasonic examination test specimens; development of demonstration administrative procedures, protocol, and personnel; and attaining regulatory acceptance of the PDI program. By the mid 1990s, these elements were in place, and the nuclear inspection industry began the process of demonstrating the performance of its ASME Section XI ultrasonic examination procedures and personnel.

Performance Demonstration Initiative (PDI) Qualification Process

Implementation of the PDI program was phased in incrementally, based on the availability of qualification test specimens and complexity of the examination. Demonstrations to qualify piping examinations for wrought austenitic and ferritic piping welds (Appendix VIII, Supplements 2 and 3), and bolting examinations (Supplement 8) were conducted first. These were followed by reactor pressure vessel clad/base metal interface (Supplement 4), reactor pressure vessel welds (Supplement 6), reactor pressure vessel nozzle inner radius examinations (Supplement 5), and reactor pressure nozzle-to-vessel welds (Supplement 7). The latest performance demonstrations to be implemented were for full structural clad wrought austenitic piping welds (Supplement 11), and dissimilar metal weld examinations (Supplement 10) from the piping outside surface. Framatome ANP's recent qualification was Supplement 14, the combination of Supplements 2 and 10. This examination technique consists of automated ultrasonic examination of the dissimilar metal nozzle to safe-end weld from the reactor nozzle and safe-end inside surface.

As qualifications were attempted for each new supplement, the difficulty of successfully completing the performance demonstration also increased. The difficulties were related to changes in weld structure and metallurgy, flaw morphology, component geometry; and transmission of sound through complex geometries, including isotropic and anisotropic materials. The robustness of existing ultrasonic examination equipment and techniques, and the training and expertise of the UT personnel are also key factors contributing to the success of initial performance demonstrations.

The PDI qualification process consists of the following key process elements:

1) Development and refinement of the ultrasonic examination procedure. Normally, the procedure is developed by the inspection organization as an independent activity prior to the performance demonstration activity. The UT procedure is typically refined to address a code examination requirement to volumetrically examine a particular component, a customer-specific need, or a range of components, such as piping welds.

2) The first phase of the performance demonstration begins with performance of the examination and collection of examination data for detection and sizing of flaws on open test specimens. Validation of the UT procedure capabilities is demonstrated through the use of open qualification test specimens.

- "Open" means the location and sizes of the flaws in the test specimen are provided to the qualification test candidates.
- Open test specimens contain both in-service and fabrication type flaws that must be detected and sized using the candidate procedure.
- The candidate analyzes the results from the open demonstrations and compares them against the actual flaw locations and sizes.
- The Performance Demonstration Administrator (PDA) reviews the open test result information against flaw truth and code acceptance criteria, and then determines if the examination procedure is ready for the second, blind phase of the demonstration process.

3) The second phase begins with performance of the examination and collection of examination data for detection and sizing of flaws on blind test specimens.

- The blind test specimens contain both in-service and fabrication type flaws that must be detected and sized with the candidate procedure. However, the candidates are not given the actual flaw locations and sizing (flaw truth).
- As with the open test, the candidate analyzes results from the blind demonstrations. The candidate reports the flaw locations and sizing results, and this information is turned over to the PDA for evaluation.
- The PDA evaluates the blind demonstration results against the flaw truth information and ASME Section XI, Appendix VIII acceptance criteria and determines if the procedure meets the detection and sizing acceptance criteria.
- If the procedure meets the performance demonstration acceptance criteria, then it is considered to be qualified. Depending on the actual scope of the examination procedure, the procedure could be demonstrated and qualified for detection or sizing or both.
- If the procedure does not meet the acceptance criteria for either detection or sizing or both, then the PDA may allow further examinations on additional blind test specimens. The PDA per-

mits these additional demonstrations as a means to assist the candidate in achieving an acceptable set of test data.

4) The third phase of the performance demonstration process is personnel qualification. Ultrasonic testing personnel who will use the subject procedure must be qualified on the procedure.

- Candidate personnel demonstrate use of the qualified procedure on blind test specimens.

- The candidate personnel must demonstrate proficiency in the use of the procedure by detecting and/or sizing a sample of flaws in the blind test specimens.

- Depending on the complexity of the UT procedure, the personnel qualification can be completed in conjunction with the procedure qualification process. Normally, at least one person achieves his or her personnel qualification by performing the procedure qualification examinations.

- Depending on the scope of the procedure, a person may be qualified for detection, or sizing, or for both detection and sizing.

The Supplement 14 Ultrasonic Examination Qualification

As mentioned above, ASME Section XI, Appendix VIII, addresses the requirements for the performance demonstration of ultrasonic examination procedures used to perform mandated in-service inspection of nuclear power plant components. Detailed within the Appendix VIII supplements are the specific requirements for implementing the various ultrasonic examination performance demonstrations.

In practice, the "Supplement 14" ultrasonic examination is automated UT of the dissimilar metal (DM) nozzle to safe-end weld, from the reactor nozzle inside surface of a pressurized water reactor. The Supplement 14 examination qualification is a combination of two different qualifications: Supplement 2, ferritic piping, and Supplement 10, dissimilar metal piping welds. ASME Section XI requires that these examinations be performed at ten-year intervals to verify the structural integrity of the nozzle to safe-end welds. This examination is normally performed in conjunction with the ten-year reactor pressure vessel weld examination using remote-operated, robotic tooling and automated ultrasonic examination techniques. This examination is one of the most difficult in-service examinations to perform, due to limited access to the weld and configuration changes from the reactor nozzle inner bore area to the piping weld. The examination is further complicated by the change in materials from the low-alloy steel nozzle forging to the Alloy 600 safe-end material, and the stainless or ferritic piping weld. Figure 2 shows a typical PWR shop-welded inlet nozzle to safe-end to elbow configuration. Note the material changes and geometry transitions between the nozzle-to-elbow area.

Framatome ANP initially attempted the Supplement 14 performance demonstration in spring 2003. Successful completion of this performance demonstration was required to support the use of qualified procedures for spring 2003 outage examinations. Ultrasonic examination techniques that had been implemented and refined over 20 to 30 years of automated reactor vessel examinations were utilized as the basis for this initial effort. During the "open" phase, difficulties were encountered in demonstrating the detection and sizing capabilities of the procedures. Several modifications were made to the UT techniques including procedural revisions and varying the essential parameters of the ultrasonic transducers. Many of these changes resulted in improvements to the detection and sizing capabilities. Due to the customer's examination schedule constraints, it was decided to begin the "blind" phase, even though all of the procedure refinements had not been completed. Also because of the customer's schedule, the PDA agreed to allow Framatome to continue with the performance demonstration effort.

Ultrasonic examination personnel implementing the performance demonstration experienced numerous difficulties during the blind testing phase. Adjustments were made continually to address each of the issues identified during the demonstration. Due to the unique challenges associated with the Supplement 14 qualification, additional refinements to the examination techniques were warranted. Flaw detection of axially oriented flaws was limited, detection of flaws was only fair with certain piping and weld geometries, and there was no repeatable detection of flaws when scanning was performed from a field-welded (rough) surface. (See Fig. 3 for typical field-welded PWR inlet nozzle to safe-end weld configuration. Note the irregularities on the inside surfaces of the welds.) To resolve the issues, all of these problems require unique solutions to examination technique essential variables; however, the schedule did not allow sufficient time to perform a root cause analysis and implement a plan to refine the examination techniques.

Despite all of the technical issues, through the hard work and effort of the Level II and III UT personnel, the performance demonstration was completed and limited qualification of the ultrasonic examination procedure was obtained. The procedure was qualified to meet the Supplement 14 criteria with the following exceptions: axial flaw detection and sizing in field welded geometries was a limitation, and depth sizing of flaws did not meet the 0.125-in. acceptance criteria or the alternative acceptance criteria of 10% of RMSP (root mean square of mean piping wall thickness). These limited qualifications were sufficient to meet the customer's needs to perform its scheduled nozzle to safe-end weld examinations, but the results clearly did not meet Framatome's or the customer's expectations. It is important to note that these results were similar to the first attempts of other inspection vendors. The results clearly indicated that significant effort was needed to improve the state of the art for the Supplement 14 ultrasonic examination.

The results from this first attempt were clearly not adequate to meet all of the customer's future needs. Thus, a detailed plan was developed that was hoped would result in a successful qualification. Following are the plan's basic elements:

- Perform a root cause evaluation to analyze all procedural limitations;

- Develop potential solutions for each of the limitations;

- Achieve consensus from technical experts on any changes and improvements that would be developed;
- Establish and implement a requalification schedule and budget;

- Attain executive level management approval of the requalification plan;

- Evaluate and validate the effectiveness of each of the technique refinements;

- Attain final technique validation by successfully completing Phase 1, open demonstrations, and gaining approval from the PDA to proceed to the Phase 2, blind demonstration;

- ◆ Implement Phase 2, blind demonstrations, and successfully qualify the Supplement 14 examination techniques;
- ◆ Successfully qualify sufficient UT personnel to perform Supplement 14 examinations scheduled for the fall 2004 outages.

The Supplement 14 requalification project was implemented in late 2003, with April 30, 2004, the scheduled date for completion. In order to address all the procedural limitations, many changes to technique essential variables would be needed. Thus, numerous hardware modifications and software revisions had to be developed and tested prior to starting the PDI Phase 1 technique validation process. A key element of the plan was the assignment and dedication of the lead Level III, appropriate Level II, and technical support resources for the duration of the effort. Executive management approval of the requalification plan was required because of the strategic importance of the project, and considerable capital expenditures as well as resource commitments were necessary. Project progress and budget were reviewed weekly to ensure compliance with plan and schedule commitments.

Despite numerous technical challenges, the hardware modification and software development and testing activities progressed according to plan. The Phase 1 (open) demonstrations, commenced in early April 2004 at Framatome's training facilities. By mid April, after completing an evaluation of all of the Phase 1 data, the PDA gave approval to proceed with Phase 2. The detection portion of the blind demonstration proceeded smoothly, by successfully demonstrating improvements in axial flaw detection and the capability to detect both circumferential and axial flaws in the difficult field-welded geometry condition. All personnel were elated with these initial results, but were cautious about the more challenging sizing demonstrations that remained.

Flaw sizing demonstrations were very demanding, due to the numerous examination scans that had to be performed on the test specimens and the significant amounts of automated examination data that had to be evaluated. The time required to review a complete set of flaw sizing data was estimated to be a minimum of 70 to 80 hours. To ensure consistency in the data evaluation process, only one UT person would perform the initial data review. In parallel with the initial data evaluation and flaw sizing, the lead Level III reviewed the data and results to validate and compile the data used to document the flaw sizing demonstration. In parallel, the PDA analyzed the sizing results as the demonstration activities progressed. As the sizing demonstrations progressed, it was determined that some minor refinements were needed to the sizing technique, which would require rescanning some of the test specimens and reevaluating the newly acquired data. The flaw sizing demonstrations took longer than originally scheduled, but were completed after three to four weeks of scans, re-scans, analysis, and evaluation of all acquired data. All data were turned over to the Performance Demonstration Administrator for its final evaluation and grading of the results.

By mid May, the final results on the Supplement 14 requalification effort were disclosed. Framatome had qualified the Supplement 14 ultrasonic examination procedure for detection and length sizing of flaws with no limitations. In addition, depth sizing was demonstrated to be within alternative acceptance criteria of 10% of RMSP (root mean square of mean piping wall thickness). Even though the Appendix VIII Supplement 14 flaw sizing criteria of 0.125-in. RMS was not achieved, flaw sizing within the 10% RMSP is considered to be an acceptable alternative. In addition to the successful qualification of the procedure, three personnel were qualified. The qualified procedure will be used to support nozzle to safe-end examinations performed during the outages this fall.

Summary

The performance demonstration and successful qualification of the ASME Section XI, Appendix VIII, Supplement 14 requirements have been the most significant ultrasonic examination qualification challenge to date. Automated ultrasonic examinations of the nozzle to safe-end welds had been performed routinely for 20 to 30 years in commercial PWR plants. The technology and procedures used for these examinations were continually improved and refined. However, the capabilities and limitations of those examination procedures were never challenged and verified until the Supplement 14 performance demonstrations were implemented. Initial attempts at Supplement 14 qualification identified limitations with the existing examination procedures and technology. Through detailed evaluation of these limitations, and with application of significant capital and technical resources, successful completion of the qualification was achieved. The final hurdle to the Supplement 14 qualification is meeting the 0.125-in. RMS sizing acceptance criteria. Many UT experts say the 0.125-in. acceptance is statistically unachievable; however, others feel that these criteria will be achieved, but only after more resources have been applied to the Supplement 14 qualification challenge. ❖