NEW PLANT CHALLENGE – PRE-SERVICE VOLUMETRIC EXAMINATION OF A HEAVY-WALL DISSIMILAR METAL WELD INVOLVING A CAST STAINLESS STEEL BASE MATERIAL

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INSPECTION REQUIREMENT

A new plant has a unique component-to-component weld configuration, as shown in Figure 1, that results in a dissimilar metal weld between a stainless steel clad low alloy ferritic steel steam generator and a statically cast stainless steel reactor coolant pump. This weld is approximately 140mm (5.5”) thick with a defined ASME Section XI pre-service and in-service inspection volume consisting of the inner one-third of the thickness including the weld, the buttering, and 6mm (0.25”) of adjacent base material. This inspection volume is specified in ASME Code Case N-799 [1]. An ASME Section XI pre-service inspection solution is required for this weld.

Figure 1: Steam Generator to Reactor Coolant Pump Casing Weld Configuration

INSPECTION SOLUTION

Reliable inspection of the required inspection volume from the outer diameter (OD) surface is challenged by the highly attenuative, heavy-walled cast stainless steel material, and the tapered outer diameter surface on the steam generator side of the weld. An inspection constraint on the inner diameter (ID) surface includes a taper on the pump side of the weld. Other inspection challenges include the multiple material types, interfaces and grain structures.

To accommodate these inspection constraints, an ID surface applied inspection approach, involving ultrasonic (UT) and supplemental eddy current (ET) methods, is being pursued.

For the weld and buttering material, and the stainless steel clad low alloy ferritic steel side of the weld, the ultrasonic inspection system must comply with ASME Section XI, Appendix VIII [2]. Appendix VIII requires performance demonstration of the UT equipment, procedure and
personnel. For the inspection volume associated with the cast stainless steel (SS) side of the weld, ASME Section XI, Appendix VIII has no UT system performance demonstration requirements. As such for the UT inspection system applied on the cast SS side of the weld, we have adopted the ASME Section V, Article 14 intermediate rigor process for examination system qualification. We have also chosen to have the supplemental ET inspection system satisfy ASME Section V, Article 14 intermediate rigor requirements.

Therefore the combined UT/ET approach uses an existing EPRI/PDI qualified WesDyne UT procedure for reactor vessel nozzle piping welds, where the materials of fabrication are similar, and an existing ENIQ-based qualified WesDyne ET procedure for the same type welds. This combined UT/ET system is intended to detect, length size and depth size service-induced flaws initiating in the inspection volume.

The UT inspections from the ferritic steel side of the weld require blind performance demonstrations of the procedure and personnel in accordance with ASME Section XI, Appendix VIII and the EPRI/PDI program since the existing qualified procedure is valid only to a weld thickness of 76mm (3”). The UT inspections from the cast SS side of the weld require non-blind or blind procedure demonstrations and blind personnel demonstrations to comply with ASME Section V, Article 14. The supplemental ET inspections require similar performance demonstrations as required for the cast SS UT system. Such demonstrations necessitate the fabrication of representative flawed test specimens.

The solution required that the existing inspection procedures be adapted to satisfy the specific weld configuration, and that a technical justification be prepared to address those inspections from the cast SS side of the weld.

**PROGRESS ON THE INSPECTION SOLUTION**

For the technical justification associated with the cast SS inspection, it was established that the most plausible damage mechanism is thermal fatigue. A deterministic fracture mechanics analysis determined the allowable flaw sizes were on the order of 38%T, where T is the weld thickness, for axial cracks and 28%T for circumferential cracks. These crack depths assumed a length to depth ratio of 10:1. Smaller length to depth ratios yielded larger allowable flaw sizes. As such target qualification flaw sizes for the case SS material were defined to be 25%T for axial cracks with length to depth aspect ratios of 2:1 to 4:1, and 19%T for circumferential cracks with length to depth aspect ratios of 4:1 to 10:1.

It is noted that the qualification flaw sizes for inspections of the weld, buttering and adjacent ferritic steel base material from the ferritic steel side of the weld are those ≥ 10%T as defined in ASME Section XI, Appendix VIII.

For the cast SS material inspection, it was established that the flaw detection rate be ≥ 80% with a false call rate of < 20%, and the flaw length sizing errors to be ≤ 19mm (0.75”) Root Mean Squared (RMS) for the UT process and ≤ 13mm (0.5”) RMS for the ET process. The target flaw depth sizing error was established to be ≤ 6.4mm (0.25") RMS.

For the inspections of the weld, buttering and adjacent ferritic steel base material from the ferritic side of the weld, the detection and false call rates and the UT flaw length sizing error are the same as above. The UT flaw depth sizing error is ≤ 3.2mm (0.125”) RMS. These criteria are defined in ASME Section XI, Appendix VIII.

To understand the impact of attenuation and localized ultrasonic velocity changes for beams in the axial direction, a series of eleven 2.4mm (0.093”) diameter circumferentially oriented side-drilled holes were placed in an existing weld coupon, which fully represented the weld, buttering, and base materials and the weld thickness. These holes were placed at a depth range of 6.4mm (0.25") to 127mm (5”) and are located on the centerline of the weld.
Tests using the UT probes intended for this weld indicated that there was a beam angle drop ranging from 1.5° to 8.5° for inspections from the cast SS side of the weld which results in a lesser accuracy in locating reflectors in depth below the surface. In addition, the focal depth range for the medium and long range focus process was effectively shortened due to attenuation losses. Two full weldment test specimens containing ID surface-connected planar flaws and lack of fusion flaws in the weld and buttering, and ID surface-connected planar flaws in the cast SS material have been fabricated for the demonstration processes. One test specimen represents an open sample for the ASME Section V, Article 14 UT and supplemental ET procedure qualifications. The other test specimen represents a blind sample for the ASME Section XI, Appendix VIII UT procedure and UT personnel performance demonstrations, and for the ASME Section V, Article 14 UT personnel qualifications. Figure 2 shows the open and blind test specimens.

The open test specimen contains flaws in the weld and buttering material and in the cast SS material. The weld contains both ID surface-connected thermal fatigue cracks and embedded lack of fusion. The implanted weld flaws consist of: five (5) circumferential cracks ranging in depth from 12% T to 93%T with length to depth aspect ratios from 1.42:1 to 2:1; three (3) axial cracks ranging in depth from 13%T to 70%T with length to depth aspect ratios from 1.65:1 to 4:1; and five (5) lack of fusion flaws ranging in through-wall depth from 4.5%T to 7.2% and located within the inner 1/3T of the weld. The cast SS material includes ID surface-connected thermal fatigue cracks with compressed EDM notch tips, and compressed EDM notches. The cast SS material flaw matrix consists of four (4) circumferential flaws ranging in depth from 22%T to 63%T with length to depth aspect ratios from 1.96:1 to 4.8:1, and four (4) axial flaws ranging in depth from 25%T to 75%T with length to depth ratios from 0.5:1 to 1.3:1.

The design, fabrication oversight, and quality control of the test specimens were performed by EPRI, and the test specimens were fabricated by Sonaspection (flaw block vendor) and Westinghouse PCI (narrow groove welding vendor). EPRI maintains control of the blind test specimen; as such details of the flaws in terms of type, number, location, orientation, and sizes are unknown to WesDyne. However the blind test specimen does contain two identical dissimilar metal welds in order to ensure sufficient grading units for the blind demonstrations.

A custom-built scanner, as shown in Figure 3, was designed and fabricated to deliver the UT and ET probes. This scanner is of a quick interlock design that requires no tools for installation. It is comprised of a mast assembly and a scanner assembly that fit individually.
through a steam generator channel head manway. It contains 2 encoded axes that are center-mounted, and drives two sled assemblies that are located 180° apart. Each sled carries four UT and/or ET probes.

![Image](image_url)

**Figure 3: Custom-Built Scanner in Mock-Up**

The UT process is based on multiple angle transmit-receive (TRL) focused probes ranging in test frequency from 1 MHz to 2 MHz. For circumferential flaw detection within the inspection volume, the UT probes consist of a short focus 70° beam, and short and medium focus 45° beams. For axial flaw detection within the inspection volume, the UT probes consists of a short focus 70° beam, a short focus 45° beam and a medium focus 37° beam. For circumferential flaw sizing throughout the weld thickness, the detection probes are complimented with a short focus 60° beam, a long focus 45° beam and a medium focus 37° beam. For axial flaw sizing throughout the weld thickness, the detection probes are complimented with a short focus 60° beam, and a long focus 45° beam. The WesDyne 16 channel PARAGON™ UT system is used for data acquisition and analysis.

Figure 4 shows the C-scan images of the short focus 70°, axial beam probes scanned over the weld, buttering and adjacent base materials in two directions. All 5 circumferential cracks are detected from both directions. Four of the 5 lack of fusion flaws were detected from either one or both sides of the weld. The remaining lack of fusion flaw is beyond the focal range of the probe type. This remaining flaw was detected with the short focus 45° axial beam probe in two directions.

Figure 5 shows the C-scan images of the short focus 70°, axial beam probes scanned over the cast SS material in two directions. All 4 circumferential cracks are detected from both directions. The images also show the detection of flaws in the weld.

Figure 6 shows the C-scan images of the short focus 70°, circumferential beam probes scanned over the weld, buttering and adjacent base materials in two directions. All 3 axial cracks are detected from both directions.

Figure 7 shows the C-scan images of the short focus 70°, circumferential beam probes scanned over the cast SS material in two directions. All 4 axial cracks are detected from both directions.
70° toward cast SS material

70° toward ferritic steel material

Figure 4: C-Scans of Short Focus 70° TRL Axial Beam Probes When Scanning Weld, Buttering and Adjacent Base Materials in Two Directions

Figure 5: C-Scans of Short Focus 70° TRL Axial Beam Probes When Scanning Cast SS Flaws
in Two Directions

Figure 6: C-Scans of Short Focus 70° TRL Circumferential Beam Probes When Scanning Weld, Buttering and Adjacent Base Materials in Two Directions

70° counter-clockwise

70° clockwise

Thus with the UT process, all flaws within the inspection volume are detectable. The flaw
length sizing results, which by procedure are addressed with the short focus 45° probe, yielded a RMS error of less than 8.6mm (0.34") on both the weld and cast SS flaws which meets the target of \( \leq 19\text{mm (0.75")} \) RMS. Flaw depth sizing using multiple probes for the weld flaws resulted in a RMS error of approximately 6.4mm (0.25") with one UT operator indicating that the target value of \( \leq 3.2\text{mm (0.125")} \) RMS may be a challenge. Flaw depth sizing using multiple probes for the flaws in the cast SS material was not considered practical using only ID surface applied examinations; attenuation limited significant ultrasound penetration into the cast SS beyond approximately mid-wall (50%T).

The supplemental ET process includes Zetec +-Point® surface riding probes operated in driver-pickup mode. Each of the two probes are skewed 45° with respect to the coil winding in order to enhance detection of both axial and circumferential ID surface connected flaws. The inspection frequencies include 100 kHz, 250 kHz and 500 kHz, with the 250 kHz frequency used for flaw detection and length sizing. The WesDyne 4 channel PARAGON™ ET system is used for data acquisition and analysis. This system is used in parallel with the UT process.

Figure 8 shows a C-scan of the axial ET scans of the weld, buttering and adjacent base materials. All 5 circumferential cracks were detected. It is noted that the 3 axial cracks are also observed given the capability of the skewed ET probes to detect cracks oriented two directions. Conversely, the C-scan of the circumferential ET scans of the weld, buttering and adjacent base materials shows the 3 axial cracks, and also detected the 5 circumferential cracks.

![C-scan of Axial ET Scans of Weld, Buttering and Adjacent Base Materials (250 kHz)](image)

Figure 8: C-Scan of Axial ET Scans of Weld, Buttering and Adjacent Base Materials (250 kHz)

Figure 9 shows a C-scan of the axial ET scans of the flaws in the cast SS material. All 4 circumferential cracks are detected and all 4 axial cracks are also observed (not indicated on the figure). It is noted that the lower amplitude responses on one side of most of the flaws are from weld material associated with the flaw implantation process, i.e. not cast SS. Also flaws in the weld are observed in the lower part of the image.

With the ET process, all the ID surface-connected flaws are easily detectable. Flaw length sizing has yielded a RMS error of 2.8mm (0.11") for flaws in the weld and 12.4mm (0.49") for flaws in the cast SS material. These results are within the RMS target of \( \leq 13\text{mm (0.5")} \).
FUTURE PLANS

This work is still ongoing. In Fall 2013, it is intended to conduct OD surface scans using both conventional and phased array UT techniques to supplement flaw depth sizing on flaws in the cast SS material and if necessary, on flaws in the weld. Such scans are intended to focus on the outer 50%T of the material.

In the 1st quarter of 2014, the UT process will undergo formal performance demonstrations using EPRI/PDI as the administrator. These demonstrations are to include: open procedure demonstration on the open test specimen for the cast SS flaws to satisfy ASME Section V, Article 14; blind procedure and personnel demonstrations on the blind test specimen welds to extend the current ASME Section XI, Appendix VIII qualified procedure to a greater weld thickness; and blind personnel demonstration on the blind test specimen cast SS material flaws. The non-blind procedure demonstration on the open test specimen is intended on establishing the flaw depth sizing capabilities for the personnel demonstrations.

The ET process will undergo performance demonstrations (non-blind – procedure, blind – personnel) internally within WesDyne following an established protocol.

REFERENCES