Study for UT Qualification of Dissimilar Weld of Pressurizer Surge Line Nozzles

Raimo PAUSSU, Fortum Nuclear Services, Espoo, Finland
Jorma PITKÄNEN, Posiva Oy, Olkiluoto, Finland

Abstract.

Surge line nozzles are until now inspected manually at Loviisa NPP. Weld crowns are ground away to base material level for UT inspection. Qualification strategy is based on ENIQ Methodology and Recommended Practices. Qualification test blocks are typically designed using similar materials as used in VVER-440 plant, and following the input data prepared for qualification, ENIQ Recommendations and ASME performance demonstration strategy.

FEM model is prepared for surge line nozzles to study the most critical areas for local stresses. This information is used to calculate critical defect sizes for dissimilar weld. Failure mechanisms are estimated to define defect types for the design of qualification test block.

Relevant materials and complete simulation of geometry of component is used while fabrication of test block. Flaw population of test block consists of cracks, lack of fusion and planar EDM reflectors. The purpose of this test block is to study different ultrasonic techniques for dissimilar weld inspection and also to find suitable crack fabrication techniques for this kind of material combination.

Detection and sizing of defects will be studied using TRL and phased array probes with transverse and longitudinal waves. The inspections are not yet finished. The final results and conclusions will be reported in conference presentation.

Introduction

Fortum Nuclear Services Ltd (FNS) is an expert organisation supporting the commission of Loviisa NPP with two units of Russian VVER-440 plant. Evaluations of failure mechanisms, calculations of critical crack sizes and preparation of input data for inspection qualification are key functions of FNS in qualification actions of in-service inspections.

FEM modelling of pressurizer bottom with surge line nozzles is part of actions to get operation license for future lifetime of plant.

Fabrication of test blocks for inspection qualification with realistic cracks and reflectors has been under continuous development inside FNS and its network suppliers for ten years. Crack production in ferritic steels and welds was new difficult area for us. Test block of dissimilar weld of surge line nozzle was used for fabrication trials of different crack types.

National research program of Inconel dissimilar welds was starting in Finland at the same time. Research program was already including overview of NDE techniques of different dissimilar welds, literary research of Jorma Pitkänen.

Test block of surge line case of Loviisa NPP (with over alloyed buttering) was offered for this program to get also practical NDE results of different mechanised inspection techniques. Research program and inspection trials are not yet finished. Preliminary results and conclusions of NDE are given in this paper. Final results are presented in conference presentation.

1. Surge Line Nozzles of Pressurizer

The construction of pressurizer bottom with surge line nozzles is presented in Figure 1.

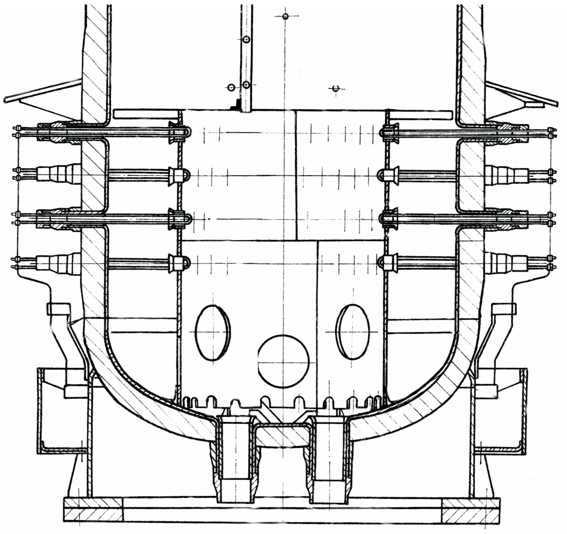
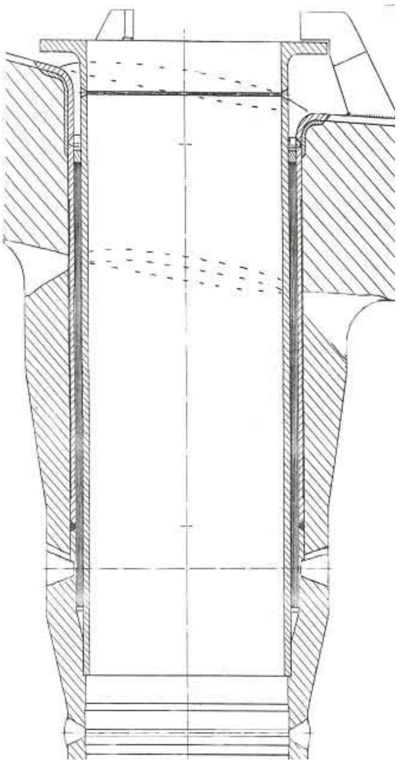


Figure 1. Pressurizer bottom with surge line nozzles

Fatigue durability of pressurizer was improved by the utility partly before commission and also during outages. The critical fatigue areas inside the bottom were improved by grinding of inside cylinder weld profiles with smooth radius and by removing stiffening supports of cylinder. The fixing of ladder was removed away from the bottom, near the critical inner radius of nozzles. Thermal heat protection of surge line nozzles and dissimilar weld is modernised afterwards during outage. The design fault of pressurizer support is eliminated by reconstruction of support weld during outages. Also the thermal insulation around the bottom and support was improved.

Dissimilar weld of surge line nozzle is a typical Russian construction: over alloyed buttering on ferritic nozzle edge and Ti-stabilised austenitic stainless reducer with sleeve welded together with austenitic stainless filler material as butt weld with partial penetration.

The present construction of surge line nozzle is presented in figure 2. Reducer and sleeve (upper end welded to inner radius of nozzle) serve as corrosion protection for dissimilar weld and ferritic nozzle. Thermal shield is assembled inside the nozzle guiding the flow and giving thermal protection for dissimilar weld and ferritic nozzle. Between thermal shield and corrosion protection sleeve there is an additional thermal folio construction to still improve thermal protection.



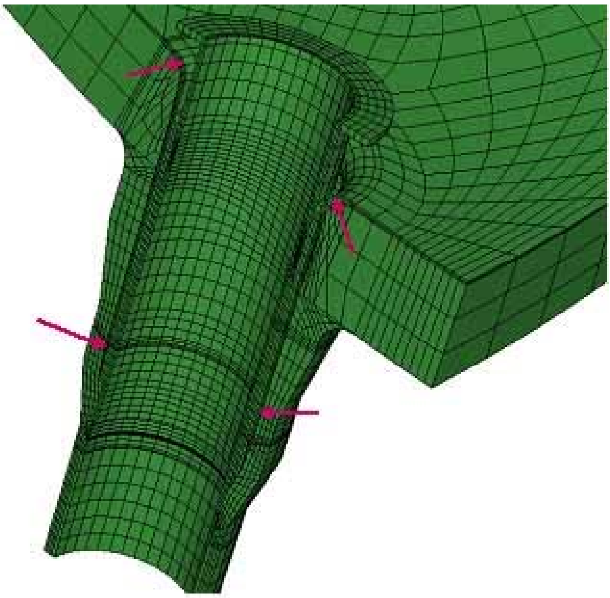


Figure 2. Surge Line Nozzle of Pressurizer **Figure 3.** FEM Model of Surge Line Nozzle

2. FEM modelling of Surge Line Nozzles of Pressurizer

The model is covering the whole bottom area with nozzles. All the loading cases during operation are considered when calculated the stresses. The critical fatigue areas are presented in Figure 3. The most critical areas (marked with arrows) are inner radius of nozzles, sleeve weld to reducer and dissimilar weld of nozzle.

Critical crack sizes and crack growth will be calculated for qualification purposes, for defining detection targets for UT examinations.

3. Test Block Fabrication of Dissimilar Weld

Test block assembly is designed to fully simulate the real component structure considering materials, welding processes, dimensions and shapes.

3.1 Materials

The base material of ferritic nozzle is S355J2H simulating Russian material 22K and austenitic stainless steel reducer is made of W1.4541 simulating Russian material 08X18H10T. Buttering layers are SMAW welded with electrode ESAB OK 67.70 (E309MoL-17) and dissimilar weld with partial penetration using electrode ESAB OK 63.30 (E316L-17).

Dimensions and shapes of parts are based on site measurements of Loviisa 2 nozzles. Welding is carried out in horizontal position and weld crown is smoothened flat to base material level by grinding as finished at site.

3.2 Flaw types of test block

Manufacturing defects (LOF) are considered as specific defect type on groove surfaces and in buttering interfaces. Constructive imperfection in weld root is present and can initiate fatigue cracks in weld root ligament. Other postulated defect types are fatigue cracks in heat affected zone of buttering in ferritic nozzle.

3.3 Flaw fabrication trials

FNS has produced LOF simulations on groove surfaces and EDM reflectors (supplied by Mekelex Ltd) as a routine job. Trials to produce fatigue cracks between buttering interfaces were carried out by FNS during the welding of buttering layers. Experience from trials revealed that fixing of cracks during overlay welding of buttering layers is needed to keep crack openings tight. Also one solidification crack was welded into interface of base material and buttering.

The main investigation was concentrating on trials to produce thermal fatigue cracks on ferritic base material and heat affected zone of buttering. Trials was carried out by Trueflaw Ltd. Experience from trials revealed that ferritic material is resistant against thermal fatigue and crack growth is really slow. Axial cracks (parallel to nozzle axis) were easier to produce than circumferential cracks of nozzle.

All the cracks were produced to nozzle part before welding it to reducer. The real crack openings after welding can be verified only by sectioning of cracks after NDE trials.

4. UT Examination of Test Block with TRL and shear wave probes

Similar dissimilar weld was under optimisation of probes at the same time of this project. Firstly VTT Industrial Systems prepared the scanning plan for the test block and examined dissimilar weld with conventional UT technique using optimised probes.

Scanning surfaces of dissimilar weld are presented in Figure 4. Mechanised UT examination is carried out using pipe scanner of VTT (Figure 5).

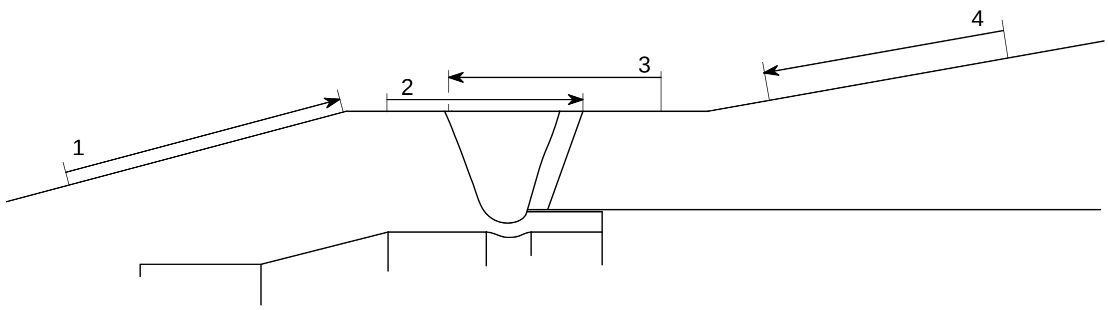


Figure 4. Scanning Surfaces of Dissimilar Weld

4.1 TRL Probes

Longitudinal focused probes with large crystal sizes and proper focus lengths showed good results by scanning from direction 1 and 2 (Figure 5.).

All the defects of the buttering area, reaching the interface of ferritic nozzle and buttering, are detected through the weld with 70°TRL2 and 65°TRL2 probes by scanning from bevel surface 1 of reducer (Figure 6). Also the soundness of ligament under dissimilar weld can be easily verified with the same probes.

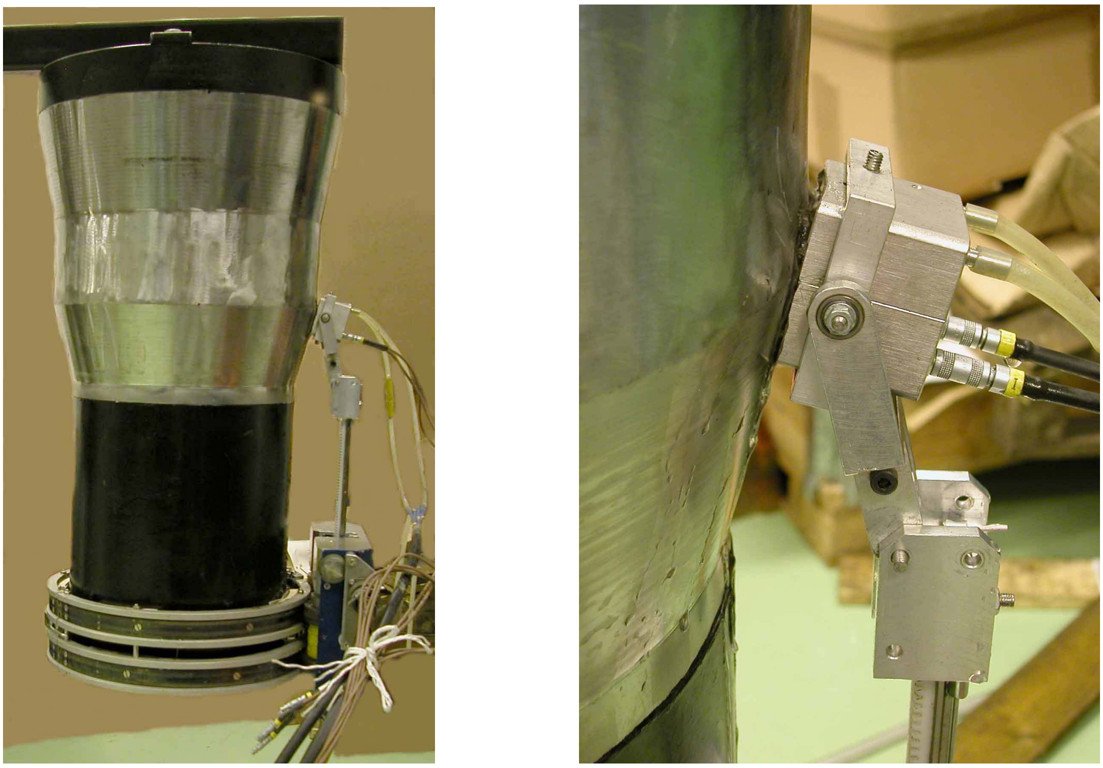


Figure 5. Scanning of Test Block with Pipe Scanner and Focused TRL Probes

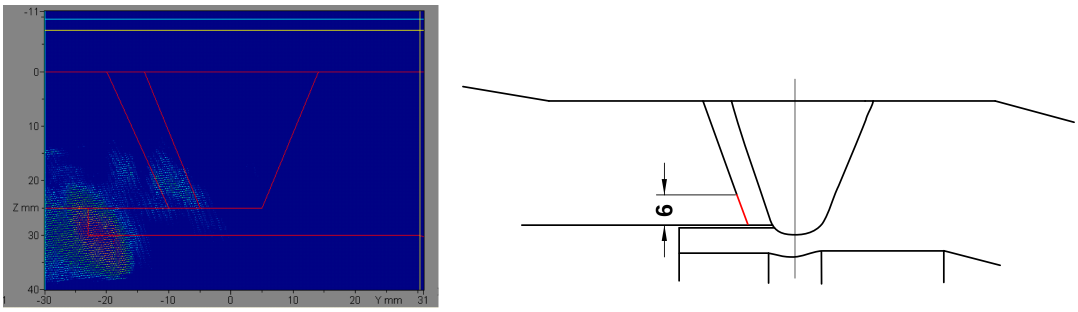


Figure 6. Solidification crack in the interface of ferritic base material and buttering

4.2 Shear Wave Probes

Shear wave probes with large crystal sizes and frequency of 1.5 MHz proved to work as expected and revealing easily those defects located on the scanning side.

5. UT Examination of Test Block using Phase Array Probes

Omniscan device of Zetec, manual scanner and probes of "EPRI qualification set" were used for UT examination using phased array probes.

5.1 Longitudinal Probes

Examination using longitudinal probes will be performed later during this summer. The results will be handled in conference presentation.

5.2 Shear Wave Probes

The probe assembly is too big for this case and for using all the scanning surfaces. Scanning direction 3 was not reasonable for coverage of ferritic side. The results show that phased array technique with shear wave probes will detect only those defects located on the scanning side. Axial defects on ferritic nozzle near the buttering can be easily detected.

6. Conclusion

6.1 Fabrication of test block with cracks

This project has given a good change to learn crack fabrication of mechanical fatigue cracks (FNS), solidification cracks (FNS) and thermal fatigue cracks (Trueflaw) by getting back fitting of UT response of cracks produced.

New materials are always a challenge for crack production. Test block of dissimilar weld has given to Trueflaw and FNS an impulse to continue the investigation of cracks production on ferritic steels. Promising progress has now been achieved.

6.2 UT examination of test blocks

National research program of dissimilar welds is taking time and so the final examination results are not yet available.

Preliminary results show that UT technique with optimised, focused TRL probes will guarantee the detection of defined flaws on dissimilar weld.

The phased array probes with shear wave probes of "EPRI qualification set" are not offering benefits for this case. Probe assembly is too big to give the best benefit in this specific case.

The phased array probes with longitudinal wave probes of "EPRI qualification set" give better results than shear wave probes. Probe assembly is too big to give the best benefit in this specific case.

7. Summary

This project has showed up some weaknesses of crack production in ferritic steel. Progress is achieved after this project by working hard on issues. Now the preparedness is achieved to produce cracks population covering all the interest areas and needed crack size range for dissimilar weld cases, both Inconel and over alloyed buttering cases.

Preparedness to fabricate test blocks (open and blind) with realistic cracks is achieved for dissimilar weld of surge line nozzles and similar cases.

Examination trials have proved that more reliable techniques are available than manual inspection technique used earlier at Loviisa NPP. Qualification case will be started in near future. Inspection technique to be qualified will partly depend on the vendor to be selected for the case.