14th Int. Conf. on NDE in the Nuclear
and Pressure Vessel Industries
Stockholm (SWEDEN), 24-26 September 1996

DEVELOPMENT OF A UT/ET PROCEDURE FOR THE INTERNAL EXAMINATION OF PWR MAIN COOLANT LOOP COMPONENTS

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Abstract

A new concept has been designed for the inservice inspection of PWR main coolant loop welds, on the basis of a robot to be introduced into the piping system. The robot can carry several ultrasonic transducers and eddy current probes, which can be scanned on the ID surface of the required areas. Both pipe-to-pipe and pipe-to-nozzle welds can be examined.
The inspection method emphasizes the detection and sizing of flaws located close to the inner surface. Customized UT transducers and ET probes have been developed to account for the coarse grain structures typical of cast austenitic base and weld material.
Blind trials have been conducted on realistic mockups of various components, to assess the actual capability of the method to detect and size real defects.

IN VIEW OF SELECTING AN NDT METHOD for the inservice inspection of the main coolant loops of its three Pressurized Water Reactors, VATTENFALL AB, the utility company who operates the Ringhals units, organized a blind round-robin test, involving four inspection companies.

A decision was made from the start of the project to consider primarily examination from the inner surface of the coolant loop. The development of the required robot is handled separately from the choice of the inspection technique, and is not dealt with in this paper.

Three mockups were selected for the round-robin trials : a pipe-to-elbow weld, a reactor coolant pump casing weld, and a main coolant pipe nozzle weld. Columnar, equiaxed and mixed grain textures can be found in the various parent materials.

A total of 27 flaws were introduced parallel to the weld centre line, in the weld material or in the heat affected zones, most of them in the inner third of the thickness. The flaws can be subdivided into four categories : mechanical fatigue cracks, solidification cracks, lack of sidewall fusion, and clusters of cracks.

The four participating teams had no previous knowledge of the number, locations and sizes of the flaws. They had to complete the examination in ten days, under the invigilation of the organizers and of the Swedish Qualification Centre. All teams used a combination of ultrasonic testing and eddy current testing.

Further details on the organization and on the overall conclusions of the round-robin are to be sought in References 1 and 2. The following outlines the technique implemented by one of the teams, and discusses the results obtained.

Examination Method

UT Technique. The UT procedure was largely based on a recent design of twin-crystal (TRL) search units (3), developed subsequently to the capability studies conducted in the PISC III programme (4,5). These showed indeed the good performance of the beam focusing technique on heavy section components made from cast or wrought austenitic steel.

The target of the development project was to obtain contact TRL probes generating acoustic beams similar to those of focusing transducers, so as to avoid the field implementation difficulties associated with the size and the weight of these.

Curved piezoelectrical elements were found to provide a solution by adding an optical focusing effect to the pseudo-focusing resulting from the convolution of the transmitter and receiver beams. The Ringhals round-robin was an ideal opportunity to test the efficiency of the new concept.

Sub-surface flaws. Beside straight beam search units, the pipe-to-elbow weld examination procedure requires 45° and 60° TRL probes with a frequency of 1 MHz.

They are complemented by a 45° 0.5 MHz unit for the coolant pump casing weld ; nevertheless, it was realized that the full 200 mm thickness could not be inspected from one surface only.

To accomodate the saddle geometry of the nozzle-to-pipe weld, refracted angles of 0, 10 and 30° are required to insonify successive parts of the weld when scanning from the nozzle ID surface. Angle search units are also scanned on the pipe ID surface.

Surface flaws. Two UT techniques were dedicated to the detection and evaluation of flaws near to the scanning surface, i.e. creeping waves and time-of-flight diffraction. In coarse grain macrostructures such as those considered here, an essential asset of the TOFD examination results from the interruption of the acoustic energy transmission by a surface flaw that would lie between the two transducers.

Flaw detection and evaluation procedure. Any signal emerging from the noise should be noted for further analysis. Flaw sizing relies on tip diffraction signals (from both TOFD and pulse-echo modes) where they can be distinguished from the background noise, contouring and amplitude drop elsewhere.

ET Technique. Eddy current probes were Ghent G3 style magnetic biased driver pickup probes containing two sets of coils at right angles to each other. They were designed to reduce the effect of magnetic permeability variations in the cast stainless steel structure as well as reduce the effect of liftoff in weld grooves during circumferential scans.

The mechanical design of one probe body incorporated a cylindrical contour of 50 mm on probe, and another probe had a hemispherical contour. Also the probes were provided with a wear surface.

The development of the technique was done on various steel blocks, including specimens representative of the materials and geometries considered in the round-robin trials, and containing realistic and well documented flaws.

The tests proved that only coils spaced close together gave acceptable signal/noise ratios. Under such conditions, surface breaking flaws varying from 0.125 mm deep to 0.5 mm deep could be detected.

NDT Equipment. A versatile mechanical scanner (PIMMS) was used for all examinations, except that of the nozzle-to-pipe weld from the pipe ID surface, which was carried out with a non-motorized mechanism.

A multichannel portable Tomoscan from RD/TECH was used for motor driving and data acquisition in pulse-echo and TOFD modes, whereas data analysis was carried out with the TomoLuis software running on a Pentium workstation.

The eddy current probe was integrated to the aforesaid mechanical devices and data acquisition system to provide color C-scan images of real and imaginary components of the signal.

Inspection capability assessment

Round-Robin Trials. Separate results were delivered for examinations conducted from the inner surface only, from the outer surface only, and from the combination of both.

Eddy current scans were performed on the pipe-to-elbow specimen only. Separate results were delivered for the UT examination and for the combined UT/ET examination.

The sensitivity of the ET procedure was reduced from the original technique development to accommodate the large changes in base material signal from region to region around the weld.

UT Results. The analysis below emphasizes the results obtained on the pipe-to-elbow specimen and on the coolant pump casing specimen, as these will be sooner exploited industrially.

Pipe-to-elbow specimen. Figure 1 shows the overall inspection performance for detection and depth sizing.

On a total of 11 flaws, 7 are detected from the inside, and 8 from the outside. However, the inside inspection detects all flaws located in the inner third of the wall thickness, which is not true for the outside inspection. The combination leads to a 100% detection score. No false call is reported.

Regarding flaw sizing, Figure 1 shows that the measured height of 9 flaws differs from the actual dimension by less than a wavelength. That accuracy must be attributed to the identification of tip diffraction signals in several cases.

Significant errors are observed on two flaws. Although both of them were correctly sized by the examination carried out from the outer surface, the combination of data recorded from both surfaces led to undersize one of them, and oversize the other.

Pump casing specimen. Figure 2 shows the detection and depth sizing performance.

All five flaws are detected. It must be noted that, as a consequence of the heavy thickness of the specimen, each one could be seen only from the nearest surface. Again, no false call is reported.

Two embedded flaws are clearly undersized. For the largest one however, the examination report stated correctly that the small indication recorded could have been produced by the upper edge of a flaw extending deeper in the specimen. Further investigations would have been necessary to confirm that hypothesis.

Main coolant pipe nozzle specimen. Seven flaws, out of a total of 11, are detected from the inner surface, and no false call is reported. A general trend to undersizing is observed.

Additional remarks. The TOFD technique turns out to outclass the creeping wave probes for near-surface flaws : their detection scores are equally high, but TOFD allows for accurate depth sizing of flaws extending down to a depth of 30 mm. In addition, TOFD does not require raster scanning, and is consequently much faster.

The selection of all other transducers appears to be justified a posteriori, as the overall performance would have been damaged, either in detection or in sizing, should any of them have been discarded.

ET Results. The results of the ET examination have not yet been analyzed in detail by the RRT organizers. The only conclusion to date is that the lowered ET sensitivity was still sufficient to detect all the surface and near-surface defects. This allowed to confirm the UT results.

Preparation of ISI

On the basis of the performances demonstrated in the round-robin trials, the technique described hereabove has been selected for the inservice inspection, to be conducted in 1997, of the two casing welds and of the inlet nozzle-to-elbow weld of one main coolant pump.

The volume to be inspected is restricted to the inner third of the component thickness, so that examination can be conducted from the inner surface only.

To date, no decision has been made on keeping or not ET in the inspection procedure. Therefore, the next paragraphs discuss only the implementation of the UT technique.

Inspection Technique. The ISI technique will be very similar to that demonstrated in the round-robin. The major changes intended are listed hereunder :

- Scanning from the outer surface is canceled from the detection procedure ; it would be kept only as a possible investigation tool in case of flaws extending deeper than the regular examination volume.
- The creeping wave probes are canceled, as they do not increase the inspection capability.
- As transverse flaws must be searched for in the pump casing welds, additional transducers are to be oriented parallel to the weld centre line.

Figure 3 illustrates the procedure currently planned.

Instrumentation. The data acquisition and analysis instruments will be those already used during the round-robin trials. The mechanical positioning and scanning of the probe holder will be assured by a dedicated robot.

Qualification. In accordance with the Swedish regulations, the examination procedure, equipment and personnel have to be qualified prior to the field performance. The qualification process, which will be invigilated by the Swedish Qualification Centre, includes open tests for the procedure and the equipment, and blind tests for the inspection teams.

Summary

The examination procedure described above was applied in the Ringhals round-robin trials, and demonstrated its effectiveness.

The flaw detection score was very high, without any adverse influence on the false call rate. Not surprisingly, flaw sizing is once more shown to be a difficult task in coarse grain austenitic steel. Some significant errors can hardly be avoided, though new techniques deliver in most cases fairly accurate size estimates.

This is particularly valid for crack-like flaws close to the examination surface, which can be reliably detected and sized with the TOFD technique.

The method is now being optimized in view of its formal qualification and of inservice inspection.

Also, the results of the round-robin trials validate the original option of performing the examination from the inside surface of the main coolant loop components.

References

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4 PISC Report Nr 34, "Report on the evaluation of the inspection results of the cast-to-cast PISC III Assemblies 41, 42 and weld B of Assembly 43", EUR 15664 EN (1995).

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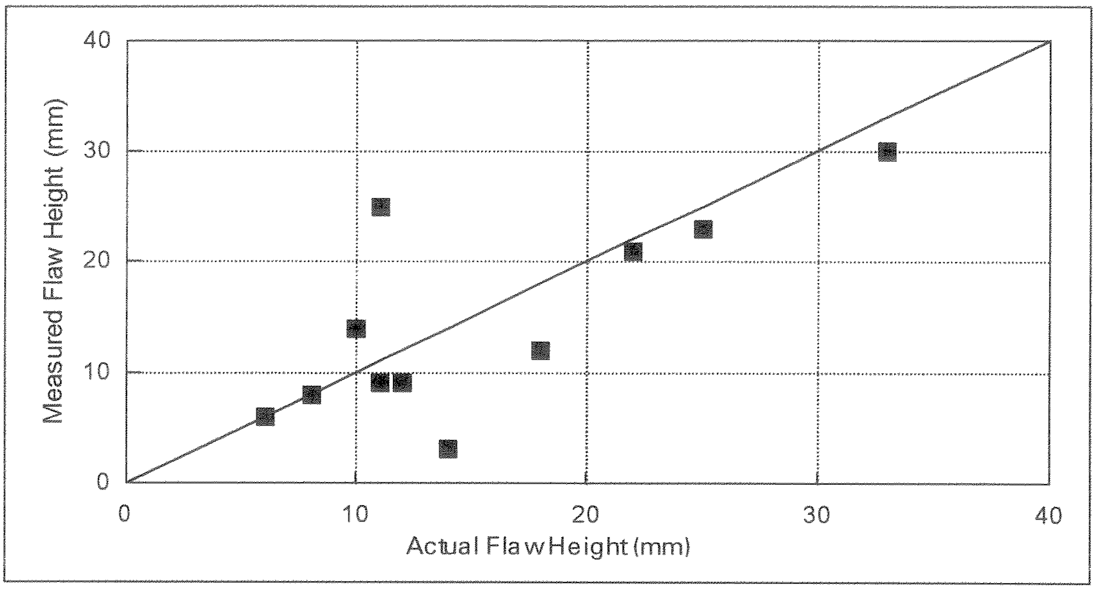


Fig. 1 - Flaw Detection and Depth Sizing Performance on Pipe-to-Elbow Specimen

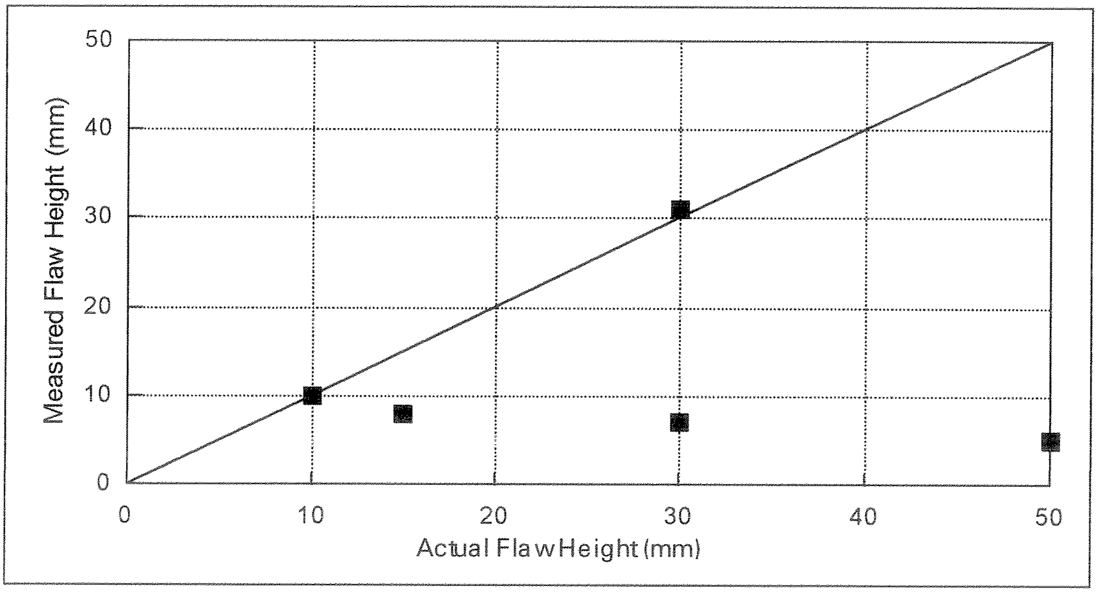
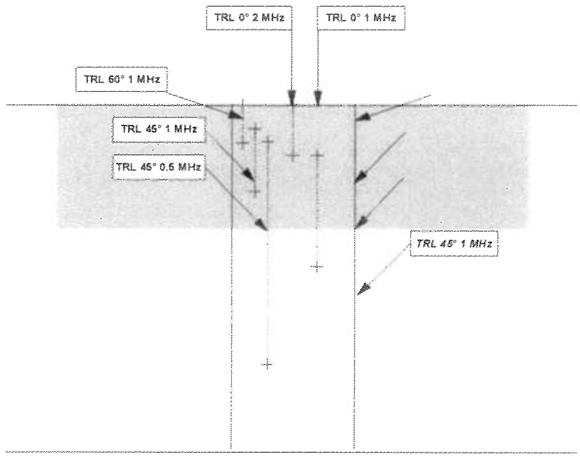
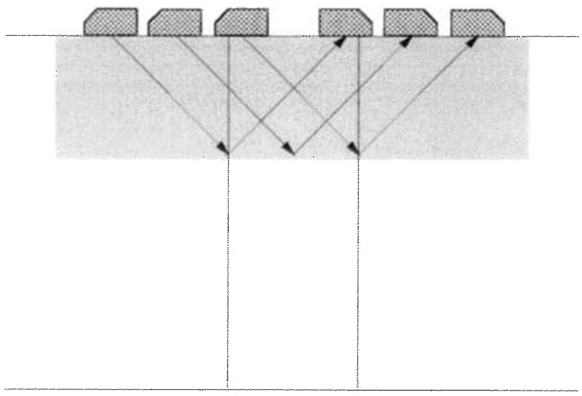


Fig. 2 - Flaw Detection and Depth Sizing Performance on Main Coolant Pump Casing Specimen

RCP CASING WELD : PULSE-ECHO EXAMINATION



RCP CASING WELD : TOFD EXAMINATION



RCP CASING WELD : PULSE-ECHO EXAMINATION
(transverse flaws)

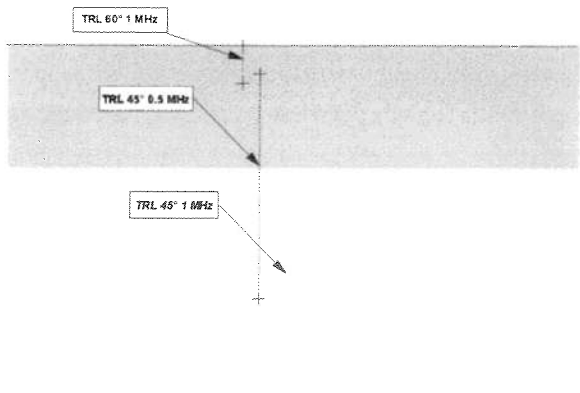
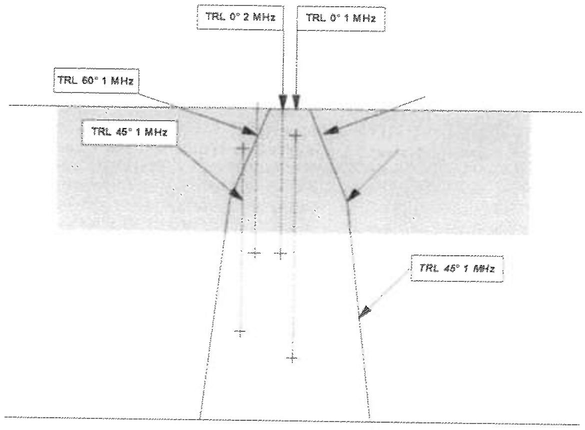


Fig. 3 a - Inservice Inspection UT Technique
(RCP Casing Weld)

RCP INLET NOZZLE WELD : PULSE-ECHO EXAMINATION



RCP INLET NOZZLE WELD : TOFD EXAMINATION

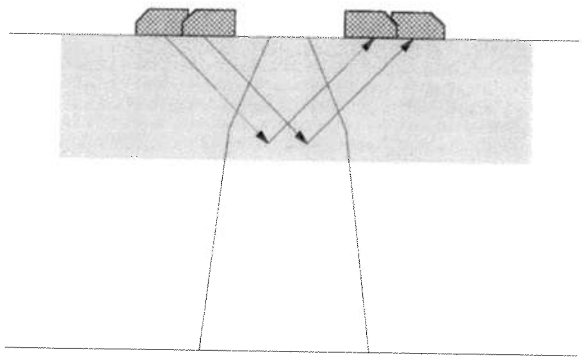


Fig. 3 b - Inservice Inspection UT Technique
(Inlet Nozzle Weld)