*7th European Conference on Non-Destructive Testing in Copenhagen, 26-29 May 1998*

# Development and qualification of a combined UT and ECT procedure for inservice inspection of PWR reactor coolant pump welds, conducted from the inner surface

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## Abstract

A new concept has been designed for the inservice inspection of PWR main coolant pump welds, based on a robot system that allows for a NDT examination from the inner surface. This paper shall address both the design of the NDT equipment, and the experience gained from the successful qualification exercises performed on the full-scale RCP mock-up at the Ringhals site.
Commercially available UT and Eddy current data acquisition systems were used. Customized UT transducers and ECT probes were developed to account for the coarse grain structures typical of cast austenitic materials. Dedicated scanning plates and electrical cabling were designed to interface the various probes and the data acquisition system to the OASIS inspection robot.
NDT procedure qualification (open trials) and NDT personnel qualification (blind trials) were performed according to the requirements of the Swedish nuclear authority. In both cases the outcome was successful. Relevant examples from the open trials shall be presented to illustrate the excellent examination capability of the method.

## Introduction

Inservice inspection of primary loop and reactor coolant pump welds of pressurised water reactors (PWR) has over the years been performed to a limited extent, due to the difficulties encountered when performing ultrasonic examinations on heavy wall cast stainless steel components. Indeed, the propagation of acoustic waves is strongly disturbed by the coarse-grain austenitic metal structure : the major problems occurring are beam skewing and distortion, high background noise and uncertainty on the propagation velocity (1).
In January 1995 however, the Swedish regulator SKI imposes new rules for the inservice inspection of nuclear power plants, including more stringent requirements regarding the volumetric inspection of certain areas for remaining manufacturing flaws and service induced defects. In addition, a performance demonstration is demanded for all NDE activities within the framework of the inservice inspection programme. A formal qualification of the NDT method, the equipment and the personnel is now to be performed, based on the demands of the utilities and approved by the Swedish Qualification Body (SQC). In order to comply with these new requirements, the Ringhals plant initiated a project, aiming at performing inservice inspection on a reactor coolant pump in the summer of 1997, and on the complete primary loop in a second phase (2). The development and the qualification process of an NDT examination method for the RCP inspection shall be adressed hereunder.

## The Ringhals examination concept for the RCP inservice inspection

A new concept was chosen for the inservice inspection. The main objective of inservice inspection is to detect service induced defects, which most often occur as surface breaking defects on the inner surface of the considered component or weld. Therefore, taking into account the difficulties induced by the statically cast austenitic structure, non-destructive examinations performed from the inner surface of the pump casing should provide improved detection and sizing capability.

Over the past decade, efforts have been made to reduce radiation exposure for NDT personnel, according to the so-called ALARA principle. This strategy inevitably results in the use of remotely operated systems. Thus, a dedicated robot system was manufactured for inspecting the reactor coolant pump from the inside (3). Operated from a graphically programmed workstation this robot system allows access to all areas to be examined, while avoiding collisions with the pump casing.

For the purpose of selecting suitable examination techniques, a round-robin test was organised at the Ringhals site, involving several NDT companies (4). Three representative specimens containing realistic flaws were to be examined during this test . Based on the outcome of the round-robin test, AIB-Vinçotte Inter was chosen to develop a combined UT and ECT procedure for the RCP casing welds and the RCP to inlet elbow weld, covering the inner third of the wall thickness. In addition, the NDT system used during the Round Robin test was to be adapted to the robot system, in view of performing the qualification exercice imposed by the Swedish regulator and the inservice inspections afterwards.

## Outline of the combined UT and ECT procedure proposed by AIB-Vinçotte Inter

The proposed procedure is largely based on a recent design of twin-crystal (TRL) search units, developed subsequently to the capability studies on austenitic steel components conducted in the PISC III programme (5,6). As the beam focusing technique yielded good results on heavy section components made from cast or wrought austenitic structures, an attempt was made 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 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 efficiency of this new concept was successfully tested during the Ringhals round-robin and was maintained in the procedure prepared for the qualification exercices.

For embedded flaws, the procedure prescribes 45° and 60° TRL probes with a frequency of 1 MHz for both weld types. For the pump casing welds, a supplementary 45° TRL probe at 0.5 MHz is required for examination of the depth range between 35 and 80 mm. In addition, straight beam TRL search units with various depth ranges are required. The examination plans for pulse-echo techniques searching for flaws parallel to the weld are shown schematically on figure 1 (RCP casing weld) and figure 2 (RCP to inlet elbow weld) . As transverse flaws must also be searched for in the pump casing welds, additional transducers of the same types are to be oriented parallel to the weld centre line.

The TOFD "obstruction method" is a complementary but essential part of the NDT examination procedure. It is based on the interruption of the acoustic energy transmission by a surface flaw that would lie between the transmitter and the receiver probes, and proved to be very efficient for detection and accurate sizing of near-surface defects in highly attenuating

materials.  Single crystal compression wave probes have been selected for the implementation of this technique.
Eddy current testing is prescribed to confirm the presence of surface-breaking flaws, and to accurately measure their length. A dedicated Ghent style magnetically biased driver pickup probe was developed. Actually, this probe type contains two separate receiver coils, for the detection of both parallel and transverse flaws. Its performance was assessed on 1 mm deep and 0.15 mm wide spark-eroded notches introduced in test specimens representative for each of the weld types.

**Design of the NDT system**

Specific requirements
The NDT equipment to be provided for the inservice inspection must fulfill a number of specific requirements. First of all, the examination is to be conducted from the inside of the pump casing, while it is completely filled with water. Furthermore, it was decided that all equipment should be controlled from outside the containment building. Moreover, the NDT system must be fully compatible with the OASIS inspection robot, and efficient troubleshooting procedures are required to reduce delay times to maximum a few hours in case of any equipment failure.

NDT equipment
A portable Tomoscan system (R/DTech) is used for recording and storage of examination data. The system is equipped with a remote 16-channel pulser/receiver unit, mounted in a dedicated splashproof housing, located in the robot housing. The eddy current probe is connected to a TC5700 unit (R/DTech) serving as a front end, and the analog X-Y output signals are routed to the Tomoscan system. This allows for a coherent data recording of both UT and ECT signals.  Position information from the various probes is obtained by connecting the encoder inputs of the Tomoscan system to a robot interface unit generating pulses compatible with incremental encoder signals. A schematical representation of the NDT system design is shown on figure 3.
Data analysis is carried out on a PC-based workstation, equipped with the Tomoluis software. Tomoluis can provide compatible graphical images of UT and ECT data, thus simplifying the integration of the examination results of both techniques.

Probe design and fabrication
Only contact probes are used. The surface of the probe shoes is machined to comply with the scanning surface in the best possible way. All probes are prepared to be used in complete immersion : the cables are moulded into the housing, leaving no connector at the probe side.

Mechanical  interface
Dedicated scanning plates were designed and manufactured to interface the various transducers to the inspection robot (see figure 4). Each scanning plate contains between 4 and 6 probes, each of them mounted into a double gimbaled support. The supports are individually spring loaded in order to insure correct mechanical contact with the pump inner surface. The vertical compliance of 35 mm should be sufficient to cope with the existing tolerances on the geometrical shape of pump casings. The use of quarter-turn fasteners allows for easily mounting of the scanning plates onto the arm of the inspection robot, even for an operator wearing protective clothing and gloves.

## Qualification and certification

To comply with the rules imposed by the Swedish regulator, a formal qualification programme was setup and witnessed by SQC. In a first step, the capability of the OASIS inspection robot was demonstrated, and positioning accuracy and repeatability were found satisfying.

The second stage consisted of the qualification of the NDT procedure and the equipment. During this stage, the examination capability of the system in terms of flaw detection, length sizing and height sizing was assessed on a limited number of flaws in "open" testblocks. All qualification exercices were performed on the Ringhals RCP mock-up, consisting of a real pump casing with an inlet elbow welded to it (see figure 5). Representative defects of various types and orientations are present in all three welds. A limited zone of the mockup is considered as an "open" testblock, while the largest part is used as a "blind" specimen. Obviously, the latter part was kept sealed during all preparation work.

Figure 6 shows ultrasonic data obtained with the TOFD obstruction technique during the procedure qualification exercice : all near-surface flaws were reliably detected, and through-wall sizing was performed with errors smaller than 4 mm. In addition, the pulse-echo examination revealed all embedded flaws within the volume to be examined, without reporting any false calls.

After the formal qualification of examination procedure and equipment, each individual of the proposed ISI intervention team was to be qualified for the tasks within his activity scope. All four candidates for data interpretation successfully performed the "blind" qualification exercice in terms of detection capability, meaning that more than 90% of the flaws were detected and correctly positioned, with a false call rate of less than 10%. In most cases, length sizing of the flaws was also performed within the required tolerances. Not all of the data interpretation operators were able to meet the stringent height sizing criteria. Clearly, accurate through-wall sizing of flaws in cast stainless steel components is an extremely difficult task, requiring not only appropriate search units and well-prepared procedures, but also a thorough knowledge of the various physical phenomena involved and extensive on-the-job experience.

A three month period, from May to July 1997, was needed to complete the qualification process.

Throughout the project, quality assurance was strongly emphasized, both during the development phase and during the site activities. Detailed working procedures for the inservice inspection were prepared and extensively tested before and during the qualification exercices . This effort resulted in EN-45001 accreditation certificates from both SWEDAC (Swedish accreditation body) and BELTEST (Belgian accreditation body). The former certificate is imposed for the performance of inservice inspections in the Swedish nuclear power plants.

## Conclusions

- A new concept was designed and implemented for the inservice inspection of PWR reactor coolant pump welds from the inside.
- The NDT system developed for this purpose passed the formal qualification exercice imposed by the Swedish nuclear authority.
- For each task, NDT operators succeeded to meet the stringent qualification criteria during "blind" tests performed on a representative specimen containing real defects.
- An EN-45001 accreditation certificate was granted for automated NDT in Swedish nuclear plants.
- The first RCP inservice inspection was successfully performed in the Ringhals 4 unit, in September 1997 : the scheduled 7-day period for the intervention was respected.

## References


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RCP CASING WELDS : PULSE-ECHO EXAMINATION

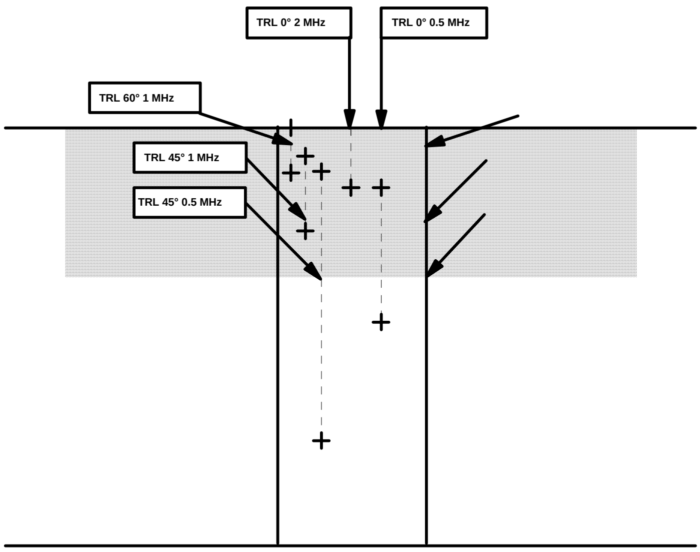


figure 1 : Pulse-echo examination plan for parallel flaws in RCP casing weld

RCP TO INLET ELBOW WELD : PULSE-ECHO EXAMINATION

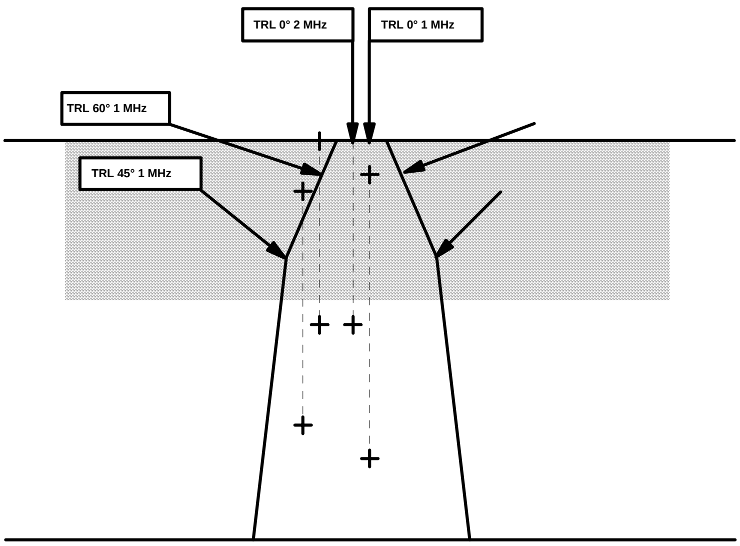


figure 2 : Pulse-echo examination plan for parallel flaws in RCP to inlet elbow weld

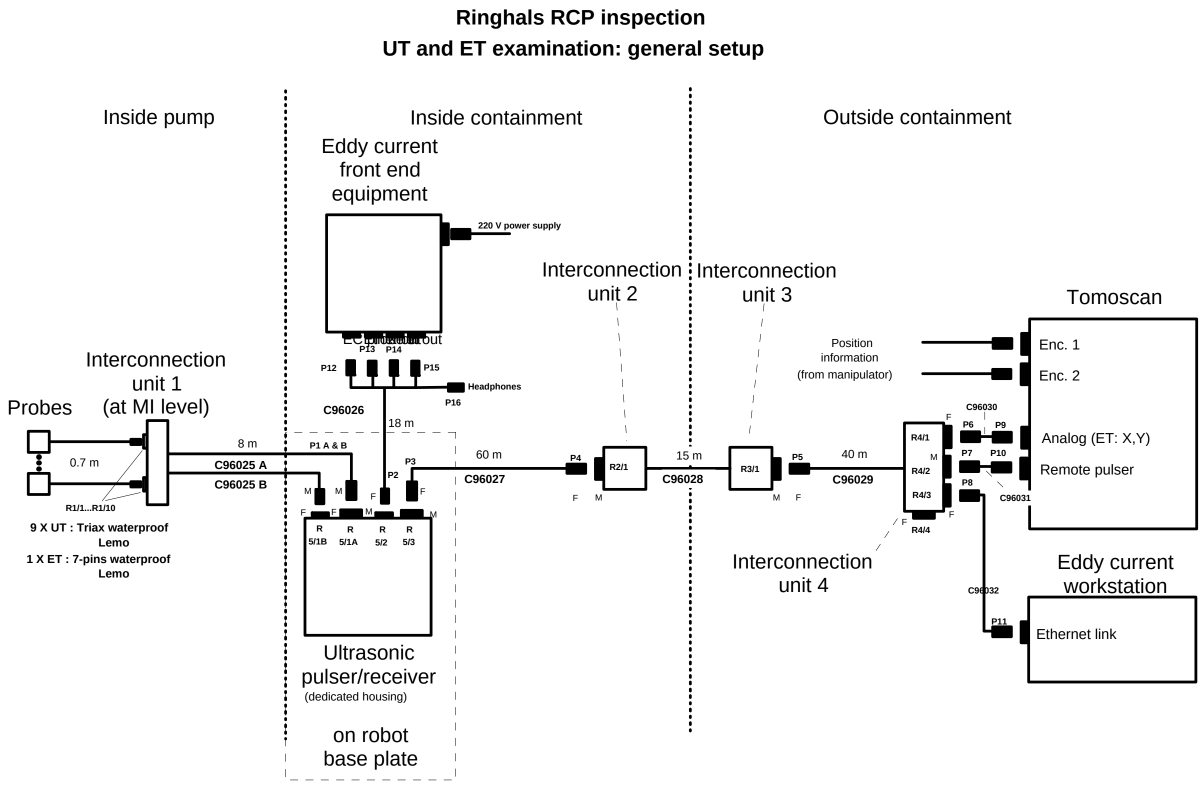


figure 3 : Schematical representation of NDT system design

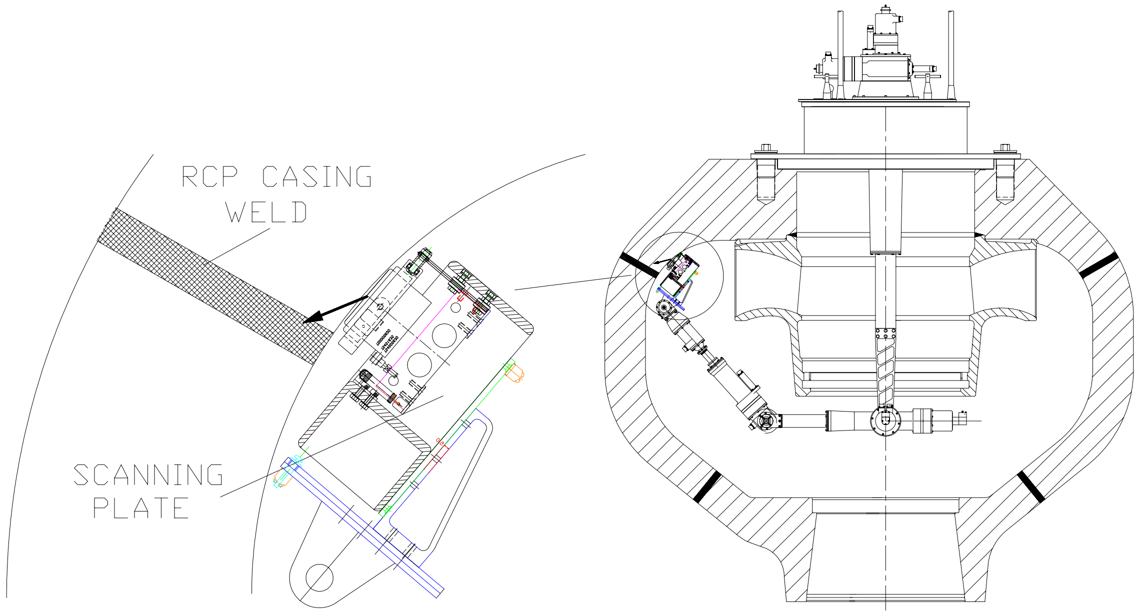


figure 4 : Scanning plate mounted on inspection robot for upper weld examination

figure 5 : Ringhals RCP qualification mock-up

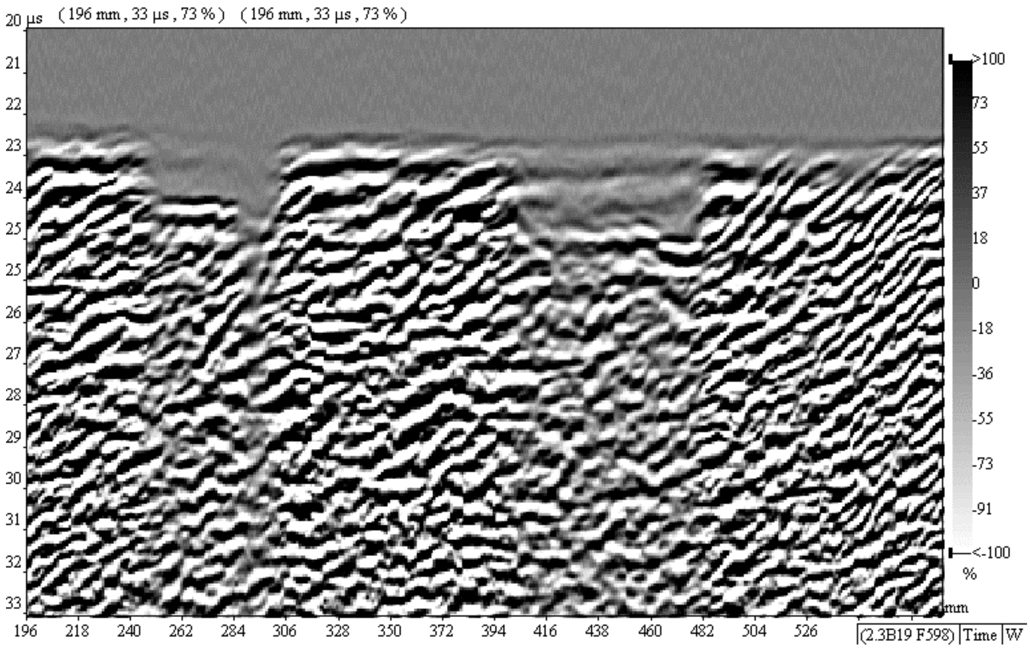


figure 6 : Real flaws in "open" pump casing qualification specimen as detected by the TOFD technique; rough cluster of small cracks (left) and smooth lack-of-fusion (right)