DEVELOPMENT OF NEW MANIPULATORS FOR PWR AND VVER VESSEL INSPECTION

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ABSTRACT
TIME, has been the key word for the inspection of Ringhals PWR vessels in Sweden. By using three parallel manipulators we succeeded to fulfill the customer demand with a complete inspection of all vessel welds, nozzles and bottom nozzles in only 5 days. This is probably a world record!

The new manipulator concept has been used twice in the reactors Ringhals 3 and 4 with outstanding performance. The next planned use will be in Ringhals 2 and in Beznau, Switzerland.

Our goal was also to minimize the time in the reactor containment with the possibility to prepare the equipment in only one day for a full vessel exam. Furthermore, the manipulators are neutrally buoyant in water and work in parallel with ROV functions totally independent of each other and with minimum support from the crane and service bridge. No pre-installation in the vessel is needed. All control systems are identical and will thus increase the redundancy. The NDE technique has been qualified according to the ENIQ and the Swedish rules. The data gathered will be sufficient for detection, characterization and sizing.

The following objects were inspected using ET, UT and VT:
- BMI Nozzle and J-groove weld
- Inlet and Outlet Nozzles, Nozzle to shell welds, inner radius and connection welds
- Circumferential and longitudinal shell welds including the bottom dome
- Areas with UCC (Under Clad Cracks)
- Radial support

A new concept for vessel head penetrations including probes will be presented.

Another concept has been developed for the VVER market. The VVER equipment can perform a vessel exam in only 8 days considering the demand to start the inspection with the water level below the nozzles. The equipment consists of one vessel wall manipulator and two nozzle ROV manipulators.

Fig. 1 All three inspection tools working in parallel at Ringhals 4

Development of tooling

PWR
DEKRA Industrial AB – Mechanized Inspection was awarded a large order from Ringhals AB. The order included development of scanners and manipulators for the inspection of the RPV Shell Welds, Nozzle Welds and BMI Welds (Bottom Mounted Instrumentation nozzles) as well as visual testing of Radial Support Welds in all three PWRs at Ringhals (units 2, 3 & 4).

The order was won in tough competition and the decisive factors were the suggested inspection strategy, inspection technique and manipulator concepts, as well as resources, competencies and a strong reputation to deliver as promised.

All manipulators have been designed to minimize the time in the reactor vessel and also in the reactor containment. The equipment can be prepared in only one shift for a full vessel exam.
Furthermore, the equipment will work in parallel totally independent of each other and with minimum support from the crane and service bridge. No pre-installation in the vessel is needed.  
The main principle with all equipment is to make them neutral buoyant in water and also to use thrusters for independent movement.  
The NDE technique has been qualified according to the ENIQ and the Swedish regulations. The data gathered will be sufficient for detection, characterization and sizing.  
The personnel resources cover all needs for development of manipulators and NDT, as well as probe design. All equipment was tested at the Ringhals test facility before the first outage performance.

Fig. 2 The nozzle tool during set up at Ringhals  

Fig. 3 The inspection team

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>All:</td>
<td>1 PM, 3 Coordinators, 1 QA/QC</td>
</tr>
<tr>
<td>Vessel:</td>
<td>3 x (1 Operator/Data Acq., 1 Tooling)</td>
</tr>
<tr>
<td>Nozzles:</td>
<td>3 x (1 Operator/Data Acq., 1 Tooling)</td>
</tr>
<tr>
<td>BMI:</td>
<td>3 x (1 Operator/Data Acq., 1 Tooling)</td>
</tr>
<tr>
<td>Analyst:</td>
<td>2 x (3 Analyst (one per insp.obj.) + 1 Super Analyst)</td>
</tr>
<tr>
<td>Total:</td>
<td>31 people</td>
</tr>
</tbody>
</table>

Fig. 4 Commissioning of the equipment at Ringhals

THE EQUIPMENT
Three completely new equipment and one replica tool were designed with the focus to allow a parallel inspection in the vessel without obstructing or delaying the other ongoing inspections.

- **SKIDBLADNER**, Manipulator for Vessel Inspection,
- **SÄRIMNER**, Manipulator for Nozzle Inspection
- **GUNGNER**, Manipulator for BMI Nozzle and J-groove weld
- **DRAUPNER**, Replica tool for BMI J-groove weld

The concept is based on the idea of lightweight and remotely operated vehicles, ROV-equipment, independent of cranes and platforms. The manipulators for nozzle inspection and the manipulator for bottom nozzles can freely “swim” between the different objects, while the vessel inspection manipulator keeps on scanning in segments. Inspection of the vessel wall is performed in sectors with a repositioning of the manipulator after that all welds in the sector is inspected.
Fig. 5 The vessel manipulator Skidladner in lower position

Fig. 6 The vessel manipulator in upper position

Fig. 7 The Nozzle inspection manipulator Särinmer

Fig. 8 The BMI nozzle manipulator Gungner
NDE

Vessel welds qualification

<table>
<thead>
<tr>
<th>Object</th>
<th>Height</th>
<th>Tolerance</th>
<th>Length</th>
<th>Tolerance</th>
<th>Ligament</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPV weld UT</td>
<td>5</td>
<td>±3.3</td>
<td>40</td>
<td>±15</td>
<td>≤3mm</td>
</tr>
<tr>
<td>RPV weld ET (W4)</td>
<td>2</td>
<td></td>
<td>10</td>
<td>±15</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 1: Qualification defects for vessel welds
The vessel welds were inspected with pulse echo & ET probes, manufactured by DEKRA.

**Nozzle area qualification**

<table>
<thead>
<tr>
<th>Object</th>
<th>Height</th>
<th>Tolerance</th>
<th>Length</th>
<th>Tolerance</th>
<th>Ligament</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPV to nozzle weld UT</td>
<td>5°</td>
<td>±3.3</td>
<td>40</td>
<td>±15</td>
<td>≤3mm</td>
</tr>
<tr>
<td>Inner radius UT</td>
<td>5°</td>
<td>±3.3</td>
<td>40</td>
<td>±15</td>
<td>≤3mm</td>
</tr>
<tr>
<td>Inner radius ET</td>
<td>2</td>
<td></td>
<td>10</td>
<td>±15</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**Table 2 Qualification defects for nozzles**

<table>
<thead>
<tr>
<th>Plant</th>
<th>Weld type</th>
<th>Defect location</th>
<th>Defect mechanism</th>
<th>Detection target h x l ±(sizing tolerance) (mm)</th>
<th>Skew/Tilt</th>
<th>Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>R2</td>
<td>Nozzle to pipe</td>
<td>Weld + HAZ ³</td>
<td>Fatigue crack</td>
<td>6 x 12 = (4.4 x 10)</td>
<td>≈10°/≈10°</td>
<td>Long</td>
</tr>
<tr>
<td>R3/R4</td>
<td>Nozzle to safe end</td>
<td>Weld + HAZ ³</td>
<td>IDSCC</td>
<td>6 x 12 = (3.0 x 10)</td>
<td>≈10°/≈10°</td>
<td>Long/Trans</td>
</tr>
<tr>
<td>R3/R4</td>
<td>Safe end to pipe</td>
<td>Weld + HAZ ³</td>
<td>Fatigue crack</td>
<td>6 x 18 = (4.4 x 10)</td>
<td>≈10°/≈10°</td>
<td>Long</td>
</tr>
</tbody>
</table>

**Table 3 Detection targets for nozzles**

**Fig. 13 Vessel welds**

**Fig. 14 Nozzle to safe end welds**
Fig. 15 RPV to Nozzle welds

The nozzles were inspected with pulse echo, TOFD and ET probes manufactured by DEKRA.

BMI demonstration

<table>
<thead>
<tr>
<th>Location</th>
<th>Defect</th>
<th>Orientation</th>
<th>Tilt</th>
<th>Skew</th>
<th>Detection target $h \times l \pm$ (sizing tolerance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fusion zone</td>
<td>Lack of fusion</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>$4 \times 5 \pm (3.5 \times 10)^{\circ}$ mm</td>
</tr>
<tr>
<td>Nozzle ID including connection weld</td>
<td>Surface breaking IGSCC</td>
<td>Circumferential / Axial</td>
<td>$\pm 10^{\circ}$</td>
<td>$\pm 10^{\circ}$</td>
<td>$1 \times 5 \pm (2.5 \times 10)^{\circ}$ mm, $2 \times 10 \pm (2.5 \times 20)^{\circ}$ mm</td>
</tr>
<tr>
<td>Nozzle OD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-Groove weld</td>
<td>Surface breaking IGSCC</td>
<td>Circumferential / Axial</td>
<td>$\pm 10^{\circ}$/ $45^{\circ} \pm$</td>
<td>$\pm 10^{\circ}$</td>
<td>$2 \times 5 \pm (3.5 \times 10)^{\circ}$ mm</td>
</tr>
</tbody>
</table>

Table 4 Detection targets for bottom nozzles

The BMIs were inspected with combination of pulse echo, TOFD and ET probes, manufactured by DEKRA. Test blocks were supplied by EPRI, Ringhals AB and SQC.

Fig. 17 Fusion face inspection, with reportable defects
Vessel Head Penetrations

The new concept for VHP inspection functions with two separate end effectors working in parallel. A probe with 4 functions has been qualified.

One end effector at a time can reach out from under the vessel head for change of probes during operation of the other.

4 different functions in the same probe:
- TOFD for circumferential defects
- TOFD for axial defects
- ET driver/ pickup
- Transducer at 0° for thickness measurement (lack of fusion indications at the interface of the J-groove weld and tubing outside surface)

The VHP equipment will reduce the inspection time by using the parallel approach as well as giving full information when using the new blade probe.
A new set of tooling is now under development for the VVER market where demands exist to perform part of the inspection with the water level under the nozzles during part of the outage.

There is also a demand to perform extensive visual inspection as well as ultrasonic and eddy current testing. The concept is similar to our PWR solution and works with two different nozzle manipulators. The concept is based on the idea of lightweight and remotely operated vehicles, ROV-equipment, independent of cranes and platforms. The manipulators for nozzle inspection can freely "swim" between the different objects.

The VVER equipment can perform a vessel exam in only 8 days considering the demand to start the inspection with the water level below the nozzles.

PERFORMANCE
The task was to perform a qualified inspection of all vessel welds including nozzles, bottom nozzles and VT of the radial supports for all 3 PWRs in Ringhals Sweden.

Technique development and qualification efforts were performed during a 2 year period and the first use was in June 2010. The second inspection was made in September 2010 on record time.

The full scope of inspection was performed in just 5 days. In September 2012 the third inspection will take place at Ringhals 2. The inspection scope covered:

- **Vessel** Circumferential and longitudinal shell welds including the bottom dome Areas with UCC (Under Clad Cracks)
- **Nozzles** Inlet and Outlet Nozzles, Nozzle to shell welds, Inner radius and connection
welds Areas with UCC (Under Clad Cracks)
- **Bottom Nozzles** BMI Nozzle, J-groove weld and lower attachment weld, 50 nozzles in total
- **Radial Supports** Visual testing of Radial Support Welds

The next inspection projects with the vessel manipulators will be the feed water nozzles in a BWR in Oskarshamn, Sweden and the vessel in the PWRs in Beznau, Switzerland. The existing qualification will be adapted to fit the requirements in Switzerland. The inspection scope in Beznau:
- **Vessel** Shell welds
- **Nozzles** Inlet and Outlet Nozzles, Nozzle to shell welds, Inner radius and connection welds
- **Safety Injection Nozzles** Attachment weld
- **Brackets** Reactor outside
- **Ligaments and core bearing area** Internal supports