Inspection of Inaccessible Areas: The Heysham Case

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Abstract. Most utility owner’s fear to have a call from their Non-Destructive Examination (NDE) group stating that “we have an indication we can’t explain”. In the Heysham case this is what happened in late 2013. During normal in-service inspection of the Heysham boiler spines one of the eight boilers indicated an anomaly placed in an inaccessible location.

During the first half of 2014 the EDF-Energy team and a number of Service companies, Westinghouse and WesDyne included, developed procedures and methods to enable WesDyne to inspect the area in question using ultrasonic and eddy current techniques. In parallel a backup solution was developed by Phoenix Ltd and an x-ray approach using a second entry point was developed by AMEC.

The essence of the inspection challenge was to inspect a 360 degree weld area. The weld area was only accessible via an 8mm gap and located ~1500 mm down the said gap. The deployment was to be executed in a 60 °C environment inside a gas cooled reactor. The inspection solution, including factory acceptance tests, needed to be developed and completed within six months.

This paper is primarily focused on presenting the rapid development process of the inspection solutions chosen and the associated lessons learned of this project.

Keywords: Boiler spine, Ultrasonic, Eddy Current, Unapproachable, Accessibility

Background

At the end of 2013 EDF Energy (EDF-E) identified an anomalous result during routine Teletesting using guided waves which was carried out at Heysham unit 1 power station at the routine maintenance shutdown. This result was found on the central support column (spine) of one of the eight boilers (1D1) attached to Reactor 1. Heysham needed to understand more about the nature of the anomalous results and its possible cause and initiated and investigation project.
This project soon became EDF Energy’s number one risk and highest profile project during 2014. The two main reasons for the high focus were:

- The extended shut down created a significant loss of generation
- If the anomalous test results weren’t properly understood and corrected lifetime production of 2.4 G Watt (until 2019) was at risk.

**Customer Request**

Westinghouse and WesDyne were approached by EDF-E in early 2014 and asked to develop bespoke inspection tooling and inspection technique to access the space where the anomalous reading was indicating.

More specifically the challenge given was to develop remotely operated tooling that would fit into a 20mm wide and 2m deep gap. This narrow slot formed an annular space between a thermal shroud and the boiler spine itself. To make the situation even more challenging the temperature of the boiler during the requested inspection was expected to be in the excess of 50 degrees C and the radiation rates also expected to be high.

![Fig. 1. Inspection area (encircled)](image)

The inspection task as initially described was to detect, characterize and size the anomaly. Actual inspection and acceptance criteria were to be developed during the course of the project but the true undertaking was to develop probes that would fit into the gap and survive the radiation and temperature levels.

Site execution was requested to mid-June. Hence we were given a six months window to develop tooling and technique, build test blocks, validate tooling and techniques, train personnel to install and service equipment in the full scale mock-up and execute on site.
Functional Requirements

Based on limited condition information WesDyne started to develop an inspection concept. The key initial specifications are presented below.

**Component Access Specification**
- V weld without cap
- Stainless steel parent material and weld material
- All couplant used to be retrieved
- Narrow gap (initially 20mm, in the end design criteria 8mm used)
- Component ~60°C
- Radiation level ~2mSv/h at 1m

**Inspection Requirements**
- Inspection area weld center line +/- 200mm
- Detection of surface breaking defects (ID and OD)
- Sizing of detected defects
- Positioning of detected defects

**Equipment Requirements**
- Able to be installed in reactor by trained “Divers”
- Robust to manage transport inside reactor
- Foreign Material protocol
- NDE instrumentation to be positioned in “cool” area

**Personnel Requirements**
- Project manager with high communication skills
- NDE UT & ET Level III to lead development
- Experienced in first of a kind project development
- Mechanical and Electrical designers experienced with remote NDE

Challenges

Besides the restricted time to develop an inspection solution there was three key challenges.

**Unknown inspection targets**

All data and in depth analysis on mock-ups indicated that the indication was circumferential and covering 360 degrees. If it was a real defect it had to be in-service induced and would consequently be initiated from either outer or inner surface.

**Unknown defect location**

As the guided waves was penetrating down the center column and the geometries keeps changing the accuracy of the location was initially given with +/- 200 mm from the theoretical weld center line of the 12.3 weld. This uncertainty in turn created some challenges for the detection technique.

**Unknown object dimensions**

As the object dimensions wasn’t completely understood at the start of the project but the time pressure forced us to initiate development prior to have a complete picture. The major challenge was the continuously changing requirements related to the available gap. During our initial meeting in January 2014 the gap was presented as 20mm at the end of the development it had shrunk to “8 mm – can be less at some points”.


## Creating the solution or How to design a Swiss watch

Basically the development concept was divided into Inspection and Mechanical delivery. However, as the time constraints was quite aggressive all development was done in parallel communication and understanding of all work streams were essential.

For example, if the probe width needed to be adjusted the mechanical team was immediately notified in order to evaluate if this was acceptable or if a new inspection solution should be pursued as an alternative. This iterative process was continuously ongoing between the work streams and was enabled by in-house production of all of the essential parts.

### Inspection concept

The team decided to focus on detection of inner (ID) and outer (OD) surface defects. As the extent was expected to be 360 degrees but not confirmed. The customer and the NDE companies decided that a detection target of 10mm*5mm surface breaking defect needed to be justified.

The as the initial inspection area was quite wide the selected solution needed to be very flexible. Inspection was to be performed from above the heat affected zone to below the thermal shield.

<table>
<thead>
<tr>
<th>Jan-14</th>
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<th>April-14</th>
<th>July-14</th>
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<tbody>
<tr>
<td>Gap 20 mm</td>
<td>Gap 16 mm</td>
<td>Gap 8 mm</td>
<td>Could be less than 8mm at places</td>
<td>Inspection</td>
</tr>
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### Fig. 2. Reduction of estimated gap over time

### Fig. 3. Inspection Volume

Stainless parent material and weld

Original Inspection Area

Standard inspection through weld

Outside surface of slope a challenge
The solution selected was to use Eddy Current for detection of OD surface breaking defects and for weld positioning along the spine axis. For defects originating from the ID and defects below the thermal shield various bespoke UT pulse echo probes was developed. The inspection area below the thermal shield areas however unlikely still needed to be covered as the inspection solution. The challenge given was to cover all areas.

On a high level the ultrasonic solution relied on low frequency 60°TRL, 70°TRL and 45°S with various focal depths. This is not an unconventional inspection solution but the height restriction of the probe posed the challenge to the probe design. The limitation in probe height, temperature and schedule drove the development team to abandon the phased array solution that from a pure NDE perspective was a most attractive route forward.

**Mechanical Concept 360 Scanner**

Access to the gap was given via a cut in the thermal shield ~2m above the area to be inspected. There is access to approximately 90 degrees of the spine circumference at this level and the opening is approximately 45 degrees. These restraints give the need to do a raster scan 2000 mm down an 8 mm gap 180 degrees from your access point!

Initially there were a number of design ideas but the selected one basically consists of three parts:

- **Frame and motor drive.**
  A frame is fitted in the opening of the thermal shield and this frame holds the vertical and rotational movements.

- **Hinged ring**
  A hinged ring is fitted into the gap and locked to create 360 degrees and then connected to the rotational motor. Three different rings was produced to compensate for the uncertainties related to the spine dimensions.

- **Probe sword**
  A curved 2 m long hinged sword is fitted down the gap and connected to the ring. In the end of the blade three probes, water spray, two cameras and lights are fitted. (refer figure 4)
Mechanical Concept Helical Scanner

In April 2014 the project was informed by the customer that they had indications that the gap could be less than 8mm at some areas. If this was the case the 360 scanner concept would not work as the ring and the blade both had their design criteria of 8mm and needed an 8mm gap 360 degrees the full length of the gap. Given this new challenge WesDyne presented a “best effort” concept to the customer named the Helical Scanner.

The basis of the concept was that “any inspection is better than none”. If we could find areas with 8 mm gap we would be able to push the probes down to the inspection area and still validate the nature of the anomaly although we might not be able to cover the whole 360 degrees. The Helical scanner was created around three major parts:

- Frame fixture
  A small frame is fitted in to the opening.
- Probe pusher and circumferential movement
  The vertical movement is performed by a probe pusher and the circumferential movement is done by moving the probe pusher outside the shroud. The circumferential movement is approximately 30 degrees and full circumferential coverage is achieved by entering the probe in 5 different angles.
- Flexible blade and turtle probe head
  A 2m and 1mm thick blade with a probe head holding one UT and ET probe under a “turtle back” to secure the probes from getting caught in obstacles.

Helical scanner was developed and manufactured within three months during the final stages of the project and was the first ultrasonic tool to go into the gap!
Figure 6: Helical scanner installed in the thermal shield opening

Schedule

Figure 7: Milestones delivered during the 6 months
On-site execution

Due to Helical scanner quick installation and flexibility EDF-E choose to start with this as the defect was expected to be present 360°. The inspection went flawless in term of execution but there was no flaw detected in the space below the thermal shield opening.

The 360 scanner was deployed to scan the “dark side of the spine”. The scanner performed a 360° scan with a perfect result and the defects was found and sized. This too was a stellar performance and the customer applauded the crew and the tool as they executed with the “accuracy of a Swiss watch”.

Conclusions

The fact that WesDyne and Westinghouse were able to support EDF-E in this urgent predicament comes down to a number of key points.

- Our long history of bespoke mechanized remote NDE equipment for complex environments
- Our understanding of development and qualification processes in various countries
- Our ability to do probe development in parallel with conceptual design of inspection solutions
- Our capability to build everything from probe to manipulator in house in order to shorten lead times and re-work.
- Our ability to quickly mobilize resources globally with nuclear experience and understanding to support the challenge ahead.

However, the WesDyne and Westinghouse delivery had not been possible had EDF-E not taken the approach to the challenge they did. Without the following we would not have been able to be successful.

- EDF-E quickly built a team of key Nuclear Service providers and pursued parallel solutions for vital areas as redundancy (NDE being one of them)
- EDF-E also created a non-hostile environment where companies normally being competitors work together for the same goal and a feeling that we all succeed together.
- Although specifications were “floating” in the beginning of the project EDF-E made sure that the suppliers had access to the information as soon as EDF-E themselves had it.
- EDF-E’s ability to establish a creative and trusting environment.
- As to further highlight the successful collaboration Westinghouse, Doosan AMEC and RR was given EDF-E collaboration award 2014.

Figure 8: Westinghouse, Doosan, AMEC, Atkins and RR receives the EDF-E collaboration award
Thanks

WesDyne and Westinghouse would never have been able to perform and support EDF-E had it not been for the support from:

- James Wenham, Project manager EDF-Energy
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- Kim Sharp, NDE Level III – EDF-Energy

WesDyne

WesDyne International is the Non Destructive Inspection branch of Westinghouse Electric Company and is a leading supplier of mechanized Non-Destructive Examination products for all inspection needs worldwide. WesDyne provides turn-key and one-off type solutions with focus on the nuclear market. The expertise spans all aspects of remote and mechanized inspections, from problem analysis & solutions generation, development and manufacturing to field deployment of personnel & equipment. Inspection capabilities cover all key NDE areas such as Ultrasonic, Visual, Eddy Current, Magnetic Particle, Dye Penetrant and X-ray.