QUALIFICATION AND IMPLEMENTATION OF A NDT BASED ON PHASED ARRAY FOR THE ON-SITE INSPECTION OF BOILER TUBES OF COAL FIRED POWER PLANTS

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ABSTRACT

EDF (Electricité De France) as a major electricity supplier has high expectations of its power plants availability and reliability. Facing an unusual number of boiler tubes failures in one of its coal fired power plants, EDF decided to perform a non destructive examination of the waterwall panels. The failures were located fireside with a wide scattering.

First, EDF organized a qualification stage to compare different available technologies and suppliers. Taking into account tubes dimension, corrosion scale and defects shape. V&M (Vallourec & Mannesmann a company of the Vallourec group) have participated to this approach by developing an ultrasonic testing solution based on Phased Array technology. Through numerical simulations, lab tests and blind tests on artificial notches and field samples, V&M demonstrated the efficiency of the proposed solution, which was finally qualified by EDF according their specifications based on a deterministic and pragmatic approach for such on-site inspection demands.

Following the qualification announcement, an inspection campaign was done in the concerned coal fired power plant. During the on-site control, V&M inspected an important amount of tubes to make a detailed mapping of the tubes condition assessment. Tubes with ultrasonic indications over the detection criteria have been replaced and analyzed in lab.

This paper provides the main results of the qualification phase and the achievements of the field examinations. It shows the benefits of the qualification to achieve the aims of the NDE and offers an overview of how a well known inspection technology used in tubes manufacturing process can be adapted in an innovative way and used for the assessment of 35 year old tubes in a power plant.

LA MAXE POWERPLANT

Waterwall failures

The EDF power plant of La Maxe, near to Metz in east of France, is a coal power-plant running two boilers of 250MW each. The boiler n°2 was facing leakages on water-wall tubes. These failures were due to longitudinal cracks on inner wall at fireside, initiated from hydrogen and creeping damages. To identify the defected zones and decide about the preventive maintenance actions to launch, the power plant was searching a relevant non-destructive examination technique able to detect such inner defects and capable to inspect a wide part of the boiler concerned by the leaking in the timeframe of the annual outage.

The tubes to be inspected are seamless tubes in carbon steel, with dimensions of 51 mm × 5.6 mm (outside diameter × wall thickness). The minimal defect to be detected has been fixed by EDF technical teams at the following dimensions: 10 mm in length, 1 mm in depth (i.e. height from the inner surface).

Before the work in partnership with V&M (Vallourec & Mannesmann, a company of the Vallourec group), two standard available techniques were tried by EDF: radiography and eddy current. The radiography was able to detect defects higher than 1 mm in depth, but 1 mm depth defects are more difficult to sort reliably on the radiograph because they are in the shadowing area close to the inner surface. In addition, the radiography examinations on site involve a lot of safety constraints: usually these inspections are done during the night shift with restrictive access to the power-plant to other persons. At last, the time of inspections required by the radiography permit to inspect only small surfaces of the water-wall panel during the time allowed by the unit outage.
The low frequency eddy current method tested by EDF was more adapted for inspecting a large zone in the boiler. However this technique has shown many false alarms during first tests, in fact the indications found by this technique didn’t show any defect after sample remove and analysis. In addition, on such tubes, the minimal defect detected by this technique is finally out of the specifications.

Therefore, EDF objective was to qualify non destructive techniques able to detect and classify the inner cracks present in La Maxe water-wall tubes with the smallest defect to be detected of 10mm length and 1 mm depth. The deadlines were very short due to fixed summer power plant maintenance in June 2012.

Vallourec proposed solution
Based on the type of defect, the material of the tubes and their surface conditions, Vallourec has proposed, based on its own experience of the inspection of the tubes produced by the group, to develop and use a specific Ultrasonic Phased Array solution approved from EDF.

This technology used in tubes manufacturing process from more than 10 years now is well mastered by Vallourec NDT experts. It is suitable for detection of thin inner cracks in a large range of material and tube thickness, and it offers the possibility to do a large and fast angular covering of the fireside thanks to electronic scanning along the Phased Array probe.

The technology used in production with encircling probe was declined to be used on site. A semi encircling Phased Array probe was used to cover a large circumferential part of the fireside of the tubes. The probe is connected to a hand-held Phased Array electronic. The acoustic coupling between the probe and the steel is done by using non corrosive ultrasonic gel.

To validate the efficiency of the ultrasonic Phased-array technique, EDF requested a qualification phase in order to define:
- NDE and industrial performances of the proposed solution
- Best parameters for the design
- Study of critical influential factors and their variation range
- Inspection procedure
The qualification phase was driven by EDF technical teams of EDF-CIT, Paris (Thermal Engineering Centre), in link with EDF-DTG, Grenoble (General Technical Direction) and the maintenance team of the La Maxe production unit. For Vallourec, the actors of the development and the qualification of the ultrasonic phased-array solution were the Vallourec Research Center (VRA), Aulnoye-Aymeries, and the powergen division of V&M France, Boulogne-Billancourt.

QUALIFICATION PHASE

The main steps of the qualification process were the following:

- Listing and selecting the influent factors on the NDE performances;
- Theoretical analysis on the impact of the influent factors by numerical simulations and technical justifications;
- Practical trials to assess the performance (mainly sensitivity, consistency and repeatability) of the NDE, divided into:
  - Open and blind tests in lab on samples with artificial defects
  - Trials on site on a mock-up and on natural defects
- Documentation of the results in a qualification report and proposal of an inspection procedure in accordance with the results and the conclusions from the qualification.

The qualification process was done in accordance with the recommendation of the EN 14748 standard: “Methodology for qualification of non-destructive tests”.

Theoretical analysis

Vallourec proposed an analysis of the main influencing parameters related to

- The technique and the tool (coverage, speed, guiding…)
- The tubes (wall thickness, surface condition…)
- The defects (depth, localisation…)

From this analysis, the following testing matrix was agreed between Vallourec and EDF:

According to this matrix, each important parameter is covered by at minimum a practical test. In addition of the results of practical tests, some theoretical analyses have been done by numerical simulations on a major part of the parameters, the parameters for which the numerical simulation was feasible and relevant.

In this paper, we describe first the main results of the numerical simulations done in this qualification process, and then some examples of the results obtained during the practical trials in lab.
Numerical simulations
Detection sensitivity

Defects of different depths have been first simulated under CIVA platform. Main result was that a defect of 0.5mm depth is detected with a signal at -3dB compared to a 1mm depth notch, which validate the detection capability of the method.

![Figure 3: ultrasonic responses for different defect depths according CIVA simulation](image)

Circumferential coverage
The circumferential coverage limits was checked by simulating defects placed at different angles around the circumference. It has been shown that the parameters of the ultrasonic system permits to cover a sufficient part of the tubes at the fireside.

To obtain this performance, a particular study was done to find the best setting of the probe command: number of element per aperture and pitch between apertures. The following figure illustrates the overlay between two consecutive aperture set on the Phased array probe. The sensitivity to a defect whatever its circumferential position (angle) remains always in a range smaller than 1.5 dB.

![Figure 4: ultrasonic responses for different circumferential positions (angle) between two consecutive apertures of the phased-array probe](image)

Wall thickness influence
After having evaluated theoretically the performance of the ultrasonic solution proposed, numerical simulations were then focussed on the impact of the main influent variations occurring on the products to be inspected and during the NDE process.

First factor studied is the potential variations of the wall thickness of the tubes. Indeed as the tubes have run since many years, we can be faced to different wall thickness of the tubes due to inner erosion phenomena. Different wall thicknesses were simulated under CIVA software. The results, illustrated on the Figure 5, show that this factor does not influence critically the NDE performance: less than 1 dB for 1.6 mm of wall-thickness reduction.
Guiding influence

For assessing the influence of the guiding tolerance which will impact the NDE process on site, two different variations were simulated under CIVA: the height between the sensor and the tube and the tilt of the probe relative to the tube (See Figure 6).

![Figure 6: simulation with a tilt of the phased-array probe relative to the tube (drawing not to scale)](image)

According to simulation results, the variations of these guiding parameters in their estimated variation ranges induce some reasonable variations on the ultrasonic responses. It have been so demonstrated that the detection of the defects remains feasible under the on-site guiding conditions limits.

Practical trials

To verify and complete the theoretical study, EDF has prepared “Open” and “Blind” tests on some selected samples containing different kinds of artificial notches made by Electro-Discharge Machining (“EDM”). The samples are of the same dimensions and surface conditions than the tubes to be inspected in the power-plant.

Trials on reference samples from EDF

The first tests were made on a sample with machined inner and outer surfaces and showed promising results. Therefore, EDF provided samples with same surface conditions than in La Maxe powerplant and with longitudinal inner notches of different shapes, depths, lengths and positions. For one of the samples, Vallourec received from EDF the detailed schematic with notches properties and localisation made (“open” tests). For another sample, Vallourec had to make the tests under EDF supervision without any information about the notches present in the samples (“blind” tests).
Vallourec demonstrated the ability of the ultrasonic Phased-Array technology to detect the different notches during both the open and the blind tests. Results of the tests on one of the sample are reported hereafter, with the ultrasonic cartography (C-scans) and the detailed results on the different notches (maximal amplitude of the ultrasonic response and signal to noise ratio SNR on each notch).

<table>
<thead>
<tr>
<th>Shape of the notch</th>
<th>Length (mm)</th>
<th>Depth (mm)</th>
<th>Angular position</th>
<th>Maximal amplitude</th>
<th>SNR</th>
</tr>
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<tbody>
<tr>
<td>Rectangular</td>
<td>10</td>
<td>1</td>
<td>0°</td>
<td>0 dB</td>
<td>&gt;15 dB</td>
</tr>
<tr>
<td>Semi-elliptical</td>
<td>20</td>
<td>2</td>
<td>~20°</td>
<td>+0,9 dB</td>
<td>&gt;15 dB</td>
</tr>
<tr>
<td>Rectangular</td>
<td>10</td>
<td>1</td>
<td>~50°</td>
<td>-1,4 dB</td>
<td>&gt;15 dB</td>
</tr>
<tr>
<td>Rectangular</td>
<td>10</td>
<td>0,5</td>
<td>0°</td>
<td>-3,4 dB</td>
<td>&gt;15 dB</td>
</tr>
</tbody>
</table>

Table 1: Ultrasonic results on some EDM notches

In addition some repeatability tests has been done on the samples, showing a spread on 10 runs lower than 4 dB, which corresponds to a very good repeatability performance for a semi-manual ultrasonic inspection process. The detection threshold fixed in the procedure has been chosen in relation to the previous results in order to secure the level of probability of detection of the NDE.
Table 2: Results of repeatability tests on a 0.5 mm depth notch

**Tests on a “mockup” waterwall**

In order to complete the qualification, some other trials have been done under conditions close to the field inspection conditions into the boiler. For that, EDF prepared a “mockup” water-wall panel (see Figure 10) composed of few tubes taken from the boiler. The test was used to assess the efficiency of the proposed ultrasonic NDE in field conditions. It has permitted to demonstrate the inspection speed performance and to check the reliability of the methods which have produced no false calls during this testing on undamaged tubes.

**Validation on samples with natural defects**

Lastly some tests have been done on the few samples with natural defects which were available during the qualification phase. Tests have been made on different tube samples previously removed from the boiler. Natural defects were found by the phased array technology and confirmed after micrographic investigations.

![Figure 10: Tests in field conditions on a mockup prepared by EDF](image)

As a conclusion of the qualification phase, the ultrasonic Phased array technology proposed by Vallourec has shown very good results for the detection of the inner cracks on water-wall tubes. The performances of this method were agreed by EDF technical team, who have consequently pronounced the qualification of this method for this application.
ONSITE CONTROL PHASE

Once the qualification of the NDE techniques pronounced, Vallourec were solicited by EDF La Maxe power-plant for making an inspection campaign on water-wall tubes during the outage of the boiler in summer 2012.

Preparation
On one hand, EDF La Maxe powerplant prepared the inspection campaign by: installing scaffolding inside the boiler, cleaning the tubes by high pressure water to remove ash deposit, and plotting the tubes numbers and levels. On the other hand, Vallourec organised an extensive training program for the participants related to safety requirements, and also some internal training of inspectors to the use of the developed ultrasonic tool. All the needed material for the inspection was also prepared on a short period.

Onsite control
Vallourec team was composed of 12 participants working in 2 shifts (morning and afternoon). The NDT experts and inspectors worked during two weeks at the different scaffolding levels to inspect more than 8000m tubes. The NDT experts from EDF were in charge to validate the respect of the use of the qualified tool and of the associated examination procedure.

Found defects were classified depending on their ultrasonic maximum amplitude, by comparison with amplitudes of notches of different depths. Tubes with defects have been marked during the examination and EDF informed so that the power plant maintenance management team was able to take rapid decisions before re-starting the boiler. They decided to cut and replace 10 tubes with the highest signal amplitudes.

In addition to the marking on site, a detailed inspection report was also delivered to EDF La Maxe power plant. In this report, inspection results were presented for each panel under a recapitulative table and a mapping with the defect locations reconstructed from the ultrasonic data records. On defective zones, cartographies (or C-scans) of the ultrasonic response in the corresponding zones were also delivered, in order to offer more information on the cracks distribution along the length and the circumference of the tubes. The detailed information allows La Maxe power plant to make targeted replacements on the next boiler outages.
**Removed tubes**

On the removed tubes, 4 samples were analyzed by Vallourec through micrographic examinations. On all the samples cut, the presence of longitudinal defects has been confirmed. An example of such confirmation is shown in the following figures. Moreover the results showed a good correlation between ultrasonic signals and defect depth confirming the classification delivered to EDF.

![Figure 14: Ultrasonic cartography of a defected zone](image1.png)  ![Figure 15: Defect on a removed tube](image2.png)

**Mutual partnership**

This project was an opportunity to work on a mutual partnership between Vallourec and EDF. The EDF CIT (Thermal Engineering Centre) helped to coordinate the different tests and assessed the speed inspection. La Maxe team accepted to open the doors for the qualification and the on-site control to Vallourec participants and to prepare the easiest working conditions. The numerous exchanges between the NDT experts from EDF DTG (General Technical Direction) in Grenoble and Vallourec Research Center in Aulnoye-Aymeries were beneficial for both parties.