DIMENSIONAL MEASUREMENTS OF STELLITED SURFACES AND CLEARANCE CALCULATIONS OF GUIDANCE DEVICES FOR REACTOR PRESSURE VESSEL INTERNALS

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ABSTRACT:

This article presents a recent development of a NDE solution for dimensional measurement of stellited surfaces and clearance calculations for reactor pressure vessel internals for an EDF contract for the CP0 and CPY 900 MWe NPPs.

The solution proposed by Omexom NDT Engineering and Services consists of an automated UT PA profilometry to inspect the various guidance devices (Slide/Key for the Vessel/lower internals interface and Pins/Inserts for the Lower/Upper Internals interface) using four different supports. The inspection is performed under water in the vessel on the lower and upper internals.

The solution is based on the mechanical development of inspection robots, the development of processing software to extract the topography of the faces. Then calculate the clearances of the various devices and justify the process and associated performance.

Ultimately, the solution obtains precise dimensions of the stellited faces of the guidance devices using the ultrasonic profilometry technique. After processing, this information is used to reconstruct the topography of the guidance face and recalculate the functional guidance clearances.
1- INTRODUCTION

The increased operating life of the equipment and management of its ageing are major challenges for the competitiveness and safety of the NPP fleet. The corresponding ageing of the equipment poses new problems and consequently requires to monitor new areas and develop appropriate inspection methods. EDF has thus decided to acquire a dimensional measurement and clearance determination process for the reactor vessel internals guidance devices.

In this context and given the experience of Omexom NDT Engineering and Services in the field of “metrological measurement” under water in a nuclear environment, an inspection process was proposed and developed.

2- COMPONENTS INSPECTED

The functions of the reactor vessel internals are primarily mechanical (centring, support, guidance, etc.) and hydraulic. From the functional assembly viewpoint, the internal structures can be split into two sub-assemblies, referred to as Upper Internal Equipment and Lower Internal Equipment respectively.

The Lower Internals (L.I.) supports the fuel elements, which are positioned and held at the top by the Upper Internals (U.I.). These two mechanically welded structures also distribute the coolant fluid in the vessel, align and guide the reactor control clusters and the core instrumentation systems.

Precise adjustments are required between the L.I. and the vessel and between the U.I. and the L.I. in order to ensure correct operation of the reactor.

Figure 1: Reactor vessel and vessel internals (Source: Didier Jacquemain/IRSN)
**L.I./Vessel guidance interface**

This guidance system comprises four guidance devices located on the 0°, 90°, 180° and 270° axes. Each guidance device consists of a key secured to the Core Support and a slide secured to the vessel. The guide faces of the key and slide are covered with stellite (cobalt based alloy). The keys are made of Z2 CN18 10 forged steel (304 L). The slides are made of NC15Fe.

![Figure 2: Slide/Key guidance system](image)

In the examination configuration, the L.I. rest on their storage stand at the bases of the keys.

**U.I./L.I. guidance interface**

This system comprises four identical guidance devices located on the 0°, 90°, 180° and 270° axes. Each guidance device comprises a guide pin secured to the core barrel and two inserts secured in a notch on the Upper Core Plate. The Upper Core Plate is thus guided and centred on the pins by means of the inserts. The inserts and pins are made of Z2 CN18 10 (304 L) steel. The vertical guidance faces of the pin and inserts are coated with a thickness of stellite.

![Figure 3: Inserts/Pin guidance device](image)

3- **EQUIPMENT DEVELOPED**

An inspection robot has been developed for each of the components to be inspected (Slide, Key, Inserts and pin). However, each robot follows the same design logic and has similar components:

- a support block for positioning the carrier,
- a vertical translation movement for the transducers along the guidance device in order to carry out the various acquisitions,
• a frame in which a support block is housed for positioning and clamping the carrier.
• a vertical translation movement driving 2 opposing phased-array transducers actuated by a geared motor and an endless screw.
• a reference mock-up.
• an immersed leaktight unit comprising all the pneumatic and electrical controls for the carrier.

Figure 4: 3D simulation of the working environment and the robots developed

The carriers are operated and docked from the loading machine by means of a rod. The carriers are controlled from the workstation by the side of the pool. All the operations are monitored by immersed remote Visual Testing (VT) equipment.

Figure 5: Poolside workstation
4- **NDE METHOD USED**

**Signals acquisition**

The technique uses two phased-array transducers configured with linear electronic scanning (16 elements focused in the area of interest).

![Linear scan schematic diagram](image)

Each transducer therefore permanently measures the distance along the Z axis between its surface and the guidance surface, or a water column whose ultrasonic characteristics are perfectly known owing to the initial calibration carried out close to the area to be inspected (reference block carried on the inspection robots).

![View of the reference block with transducers mounted facing](image)
The two opposing surfaces are scanned simultaneously, allowing a differential measurement with no relative movement of the transducers, in order to increase the measurement precision. The distance between transducers is known as a result of the initial calibration.

The Cscan image is therefore obtained on the one hand by electronically scanning all the elements along the horizontal X axis and, on the other, by the translation movement of the transducer holder along the vertical Y axis. The dimensional measurement pitch is 0.3 x 0.2 mm producing a compact grid of the areas to be inspected.

Data processing, surface modelling

The reconstruction of each stellited surface is then made in several steps using two UT software, software linked to the UT generator and SOFOCLE (software developed for this process by Omexom NDT E&S).

The processing steps are summarized in the following logic diagram:

1- Check on quality of signals and extraction of the Ultrasound Path (UP) associated with each Ascan
2- Determination of the distance between the two transducers
3- Correction of the attitude and tilt defects linked to the displacement and operation of the carrier
4- Detection and automatic correction of any aberrant UP values
5- Positioning of the coordinates system of the component in order to take the measurements
6- Dimensional measurements and creation of a scatter chart file

![Figure 9: Cscan view associated with a stellited face of a demonstration mock-up (slide)](image)

VQ and extraction of UP.  Correction of faults linked to implementation, aberrant points and coordinates system positioning (SOFOCLE).  Scatter chart file associated with stellited face

![Figure 10: View of surface modelling processing steps](image)
Clearances calculation

The clearances are calculated after processing of the four stellited faces related to a guidance device. This calculation is made with the WACS software, a specific software developed by Omexom NDT E&S during the project.

Three main steps are used to calculate the clearance of a guidance device:

1- Positioning of a common reference point between the male component and the female component
2- Determination of a point of contact on the most damaged face
3- Calculation of the residual clearance on the opposite face

Figure 11: View of the processing steps for calculating clearance with the WACS software

The final result of the processing allows measurement of the topography of each of the guidance faces and provides a colorimetric chart of the clearance at all points on the guidance device.

5- PERFORMANCE DEMONSTRATION PROCESS

The complete process was demonstrated in two separate steps.

The first phase consisted in developing robots and carrying out an empirical demonstration of the performance of the process. This demonstration was based on numerous tests on mock-ups in order to produce an overall statistical determination of the performance of the process and validate the clearance calculation approach.

In accordance with the customer’s specifications, the performance of the dimensional and clearance measurements were estimated at being less than:

- 0.10 mm on the dimensional measurements
- 0.20 mm on the clearance measurements.

Blind test on mock-ups provided by the customer confirmed these various points.
The second step then focuses on a technical justification such as an RSE-M French nuclear code Qualification in order to consolidate the demonstration file.

This qualification is thus aimed at demonstrating that the various parameters that could influence the measurement or clearance calculation have been taken into account, estimating the measurement uncertainties associated with each of these parameters at the bounds of the variation range and the statistical sum of these various uncertainties.

The following flowchart summarises the performance justification steps.

![Flowchart: Process justifying the performance and the calculation approach](image)

*Figure 12: Process justifying the performance and the calculation approach*
6- CONCLUSION

Through this project, Omexom NDT E&S drew on its experience of ultrasonic metrology in a nuclear environment in order to provide a new inspection process.

This process enables the licensee to ensure that the guidance clearances between the vessel and the lower and upper internals are compliant, enhance its operating experience feedback with regard to the ageing of the NPPs and adapt its maintenance strategy as necessary.