Ultrasonic control system for Superphenix steam generator tubes

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ABSTRACT

An ultrasonic testing system for Superphenix steam generator tubes, and its performance are presented.

The technical specifications for flaw detection, flaw sizing and inspection speed, the complexity of the inspection (tube length and tube geometry, sodium deposits on tube outer surface) lead FRAMATOME to propose a new system based on a phased array technology.

1 - INTRODUCTION

The aim to improve the in service inspection possibilities of Steam Generator tubes of Superphenix (SPX) has lead the operating company, NERSA, at the beginning of 91, to issue an international call for tenders for the design and supply of an ultrasonic inspection system, having performance never reached so far.

Considering the helical geometry of the tube bundle (357 tubes in incoloy 800 ø 25 mm, thickness 2.6 mm), the great length of individual tubes (~ 100 meters) and the presence of residual sodium on the external wall of the tube at the time of inspection, after the steam generator has been drained, the usual inspection techniques are impracticable.

The Eddy current are disturbed due to the presence of sodium residues, with the consequence that the signal can be misinterpreted.

The spinning ultrasonic probe cannot perform a complete inspection of tubes of great length in industrial conditions. Its translation speed, limited to about 3 meters/hours, would have incurred excessive inspection duration. Therefore, an alternative solution had to be investigated.

FRAMATOME, being a designer and manufacturer of steam generators had perceived and anticipated the evolution of in service inspection requirements; this enabled FRAMATOME to offer to EDF, in 1992, a new concept of ultrasonic probe, patented, under the trade mark NOVCAPT.
This system based on a phased array probe, combines the advantages of the high inspection speed of Eddy currents, and the sensitivity of detection and defect sizing of ultrasonic waves.

After a convincing demonstration of suitability, it has been entrusted to FRAMATOME and ANSALDO in 1993 the realization of the new inspection tool of which completion and the final acceptance by EDF was pronounced during the second half of 1996.

2 - TARGETTED FLAWS

At the time of in service inspection of S.G. tubes of SPX, two types of flaws have to be looked for.

Défauts type 1

Défauts type 2

2.1 - Type 1 flaws

These are loss of thickness generated on the outer surface of the tube by:

- wastage (water/sodium reaction)
- wearing due to loosening of the strips-screws-jumpers system
- loss of thickness in manufacturing (grinding mark)

The detection threshold is fixed at 10% of the thickness of the tube, that is to say a depth 0.26 mm for a dished hollow defect Ø 3 mm (Ø 1.7 mm area).

The sizing of this flaws must achieve a precision of ± 0.1 mm for the depth and ± 1 mm for the length.
This type of flaws has to be detected over the whole tube length.

2.2 - **Type 2 flaws**

These are plane defects (crack-like), generated and/or propagated in service.

These cracks can stem from creep-fatigue, thermal fatigue, and stress corrosion. The study of sizing and testing of S.G. concept validation have lead to favour the search of circumferential internal cracks, mainly located in the H.A.Z. of welds.

The detection threshold is fixed at 10 % of the thickness of the tube, that is to say 0.26 mm depth for a notch of 1.5 mm length.

The sizing of a notch with 0.78 mm depth has to be realized with a precision of ± 0.5 mm for the depth and ± 1 mm for the length.

2.3 - **Locating the flaws**

Flaws have to be located at ± 50 mm from the strips-screws-jumpers system (supporting element of tubes).

For type 2 flaws, situated in H.A.Z., they have to be located at ± 1 mm from weld axis. Moreover, their angular position in the section of the tube, has to be determined at ± 45°.

2.4 - **Special requirement**

The inspection duration of one whole tube must be about one hour. The aim is to examine the full length of the tube, including the farthest weld (S7).
3 - DESCRIPTION OF INSPECTION SYSTEM AND CONTROL DEVICES

The inspection system is composed of:

- One phased array transducer,
- On-board electronics fitted close to the transducer (multiplexer, emitters, receivers),
- An Eddy current module providing the detection of supporting element of tubes in order to perform the pre-location of a possible defect,
- The umbilical cable of length 135 meters, assumes the electrical and mechanical links between the active part of the probe and the data acquisition system.

- Electronic data acquisition and preprocessing system.

This system is made in order to monitor and to supply the ultrasonic probe, to build the focused beam, the amplification, the demultiplexing, the corrections of gain between channels, the digitization and the digital preprocessing of the ultrasonic signals from this probe.

The acquisition rack is supplied by NDT Systems.

- Computer system

The computer system which permits the storage, the treatment and the display of data is contained inside the FRAMATOME Analysis Rack.

- Data processing

Two programs are used:

- The supervisor software MUSTANG has been conceived and developed by FRAMATOME. It manages acquisition and the analysis of U.T. signals during SPX SG tube scanning.

  It controls the module for detection (type 1 and 2 defects) and sizing (type 1 defects).

  It manages the storage of data which are transmitted and recorded on a disc at the analysis user interface.

  It runs in real time on one HP 9000 Model 743 computer.

- LODITUS software

  This software has been conceived and developed by CEA/STA.

  This software (modular) is a data processing tool used for the detection by U.T. of circumferential defect (type 2) inside the SPX S.G. tubes.

  It performs the detection and the sizing of type 2 defects mainly in the welding area, but also in the base metal of tube.
POSITEUS system

This system provides water filling and translating motion of the probe. It has been manufactured by the ANSALDO Company.

4 - OPERATING PRINCIPLE

The design utilises a piezo-electric multi element transducer laid out in a ring and driven by electronic switching.

- Electronic focusing

Multiple adjacent piezo-elements are excited to make "an opening". By acting on the phase between each elements of this opening, a focused beam can be generated. Further geometric axial focusing is obtained by the concave shape of the elements.

The beam is designed to rotate electronically by advancing one by one the group of activated elements to form a new opening and continuing in a similar way.

This enables the complete tube section to be examined without the need for mechanical rotation of the probe head.

Principe

Balayage Focalisation du faisceau
5 - **INSPECTION SPEED PERFORMANCE**

The translation is the only probe movement which is necessary for tube inspection.

The ultrasonic beam draws a helical movement with a rotation speed greater than 6000 rpm.

For the detection of type 1 and 2 defects, the inspection speed is greater than 3 m/minute.

Useful life for both the probe and the umbilical cable is set at 150 moves forth and back.

6 - **TECHNICAL RESULTS OBTAINED**

The performance and endurance of the system have been confirmed in a representative mock-up of tube bundle, including artificial and natural defects.

**Type 1 defect**

The first type of defect which has to be detected is a superficial loss of thickness located on the external wall of the tube.

The detection of several kinds of loss of thickness has been tested. The results of some examples of detection and sizing of typical defects are detailed hereafter.

a) **Dished hollow defects**

Two defects of this kind located in the weld S7 zone Ø 3 mm depth 0.26 mm and depth 0.52 mm have been detected and measured. The sizing of remaining ligament is obtained with an accuracy better than 0.1 mm.

b) **Wastage**

A real wastage created by water/sodium reaction has been perfectly detected, its measured depth is 0.6 mm.

c) **Manufacturing defect**

Two round file marks of few tenths of millimeter, have been detected in the weld S7 zone.

**Type 2 defects**

This type of defect concerns internal circumferential crack. The sizing is realized with the help of the LODITUS software created by CEA/STA.

The corner echo, in all cases, permits the detection of circular emerging cracks on the inner surface of the tube along its entire length (Heat Affected Zone or elsewhere).
The position in depth of the maximum diffraction echo is taken with the help of the a real segmented B-SCAN display.

After detecting one indication during the first travelling at speed 50 mm/s, the conic probe runs back quickly to scan 30 mm along the zone containing the indication. The scanning of this zone is made at low speed (3 mm/s).

The whole digitized RHF signal is stored.

The presentation of a real segmented B-SCAN display enables the sizing according to the above principle.

a) Notches

Length 3 mm, depth 0.78 mm )

) in weld S7 zone

Length 1.5 mm, depth 0.26 mm )

The detection and sizing of both notches have been perfectly performed.

b) Cracks in Heat Affected Zone

(obtained by thermal fatigue in CEA Laboratory)

The detection and the sizing of both cracks is performed.

Checking of the sizing of the depth will be carried out later.

c) Notch of depth 0.52 mm (20 % of thickness)

The sizing calculated by the LODITUS software gives a result of 25.9 % of thickness, against 20 % actual size.

7 - CONCLUSION

The use of the ultrasonic phased array technique for the inspection of tubes constitutes a great technological step forward.

This will allow the inspection of SPX GV tubes, ensuring both the detection threshold and accuracy of characterization, compatible with a depth of defect within the range set by the fracture mechanics analysis, at acceptable inspection rate for carrying out the inspection program of the G.V. bundle, and without penalisation of power station availability.