The JASPER System, an Innovating, Competitive Tool for Rod Cluster Control Assembly (RCCA) In-Service Inspection

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Abstract. Taking benefit from the experience of the AREVA NP group, a new tool for the inspection of rod control cluster assemblies (RCCA) was jointly developed by Intercontrôle and AREVA NP Fuel Division. The valuable know-how of R/D Tech (today Zetec) engineers in the field of UT signal spectrum analysis was a key factor of success in the development.
JASPER (an acronym for Joint Advanced System for Performant Examination of RCCA) combines three measurements, one of which is an innovation:
- Profilometry using a time of flight measurement, for the outer dimensions of the clad
- Eddy current detection of cracks
- Direct measurement of the rod wall thickness by spectrum analysis of the UT echoes, thus adding considerable interest in the examination process.
UT measurements are performed on the whole length of the rod, including the weld of the lower cap. ET measurements are performed on the lower length of the rod.
UT data are systematically recorded and analysed for detection and characterization of indications, with no retest. ET measurements are triggered upon request of the Utility, depending on the age of the rod. Data acquisition and processing thus require a constant duration for each assembly; the inspection duration is actually shortened by a 20% factor.
The technique was qualified in-house by a number of tests.

1. Introduction

Control rods in Rod Cluster Control Assemblies (RCCAs) are 4m long, stainless steel tubes, the outer surface of which has received specific treatment, aiming at increasing their resistance to wear (chromium coating or ion nitriding). These rods undergo heavy mechanical and thermal cycling during operation that inevitably create defects. The inspection of RCCAs for the detection of such defects has been carried out by Fragema since 1985 then by Intercontrôle since 1990. The merger of the companies in the AREVA group and more specifically in the AREVA NP structure created synergies which have resulted in the development of a new inspection tool, tailored to meet the new requirements of the Utility in terms of productivity and accuracy in defect location and sizing: JASPER.

***** Intercontrôle, subsidiary of AREVA NP, an AREVA and Siemens company.

The objective of the inspection is to detect and characterise the following degradations on the coated rods of any type of PWR 17x17 RCCAs :

- « wear»,
- « through-clad penetration »,
- « swelling»,
- « cracks »,
- cumulated degradations : « crack+ swelling » or « swelling + wear ».

The JASPER system has successfully gone through the steps of qualification by EDF and still has to be implemented on-site twice to be declared qualified.

2. Description of the system

2.1 Mechanical equipment and control system

The manipulator (see Figure 1) in the JASPER system consists in a series of superposed plates supporting:

- centering devices for guidance of the rods,
- NDE probes (UT and ET) :
  - twelve UT measurement probes and one reference probe,
  - twelve ET measurement probes and two reference probes ; there is one ET reference probe for each set of six ET acquisition probes,
- the elevation encoder,
- a back-geared motor with encoder enabling rotational movement of the UT probes,
- connection boxes for all probes (ET and UT),
- pressurised cables for NDE signals and command control
- four guidance vertical plates to ease positioning of the RCCA handling tool on the manipulator.

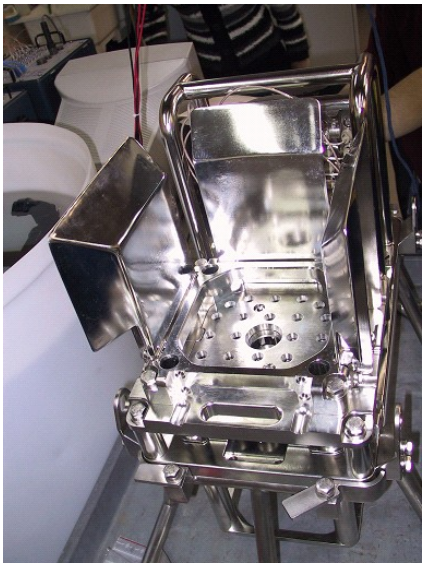


Figure 1: The manipulator

The holes in the inlet plate are chamfered in order to ease insertion of the RCCA in the manipulator.

A specific module pressurises air and distributes it in the cables and the immerged modules in order to keep the pressure at a higher value than that of the water in the spent fuel pool and thus avoid any intrusion of water.

2.2 ET equipment description

The ET instrument is an ET board integrated in the UT instrument Tomoscan (Zetec). Twelve encircling coils and two on-board balancing coils are connected to the instrument via a multiplexer.
Frequencies: 160 kHz and 500 kHz.

Descent speed being in the range of 3m/min to 5m/min, the sampling rate synchronized with the elevation encoder corresponds to one point per 0.5 mm

2.3 UT equipment description

The UT instrument is based on the Tomoscan III (Zetec).
The main features of the twelve UT transducers are:

- Central frequency : 15 MHz,
- Focal spot diameter : 0.25 mm

A thirteenth UT transducer is mounted on the system: it is the «reference probe». It is used to measure the speed of ultrasounds in water during the inspection. The probe includes a transducer aiming at a fixed target and the water path of which has been measured with high precision when the probe is characterised. This value is then used to measure the actual speed of ultrasounds in water during RCCA inspection.

Figure 2: Detail of the UT probe rotation system

2.4 Software

UT and ET data are processed by dedicated programs:

- Grappa is for ET data analysis
- Neptune characterises indication detected by UT.

3. Description of the inspection cycle

3.1 Data acquisition cycle

Control rods are examined in the spent fuel pool, in the fuel building. The pool is filled with borated water, the temperature of which is between 20° and 50°C.
The examination system is placed on the fuel elevator of the pool.

Each RCCA is transferred from its storage cell to the examination system using the specialized handling tool which also ensures the vertical movements (down then up) of the RCCA in the inspection head.

The assembly is moved up and down in the examination system by the RCCA handling tool of the NPP. The manipulator is placed on the fuel elevator. Each rod is examined using ET on the way down and UT on the way up. The twelve UT transducers rotate with a speed controlled by the handling tool speed and the axial encoder, in order to keep a constant examination step. Twelve rods being examined simultaneously, the complete assembly is thus totally examined in two passes after one rotation at 180° of the assembly.

The phases of a standard « two faces » acquisition mode are:

1. Video identification of the RCCA (underwater camera and surface camera, to correlate the position identification with the mark **(two** screen captures),
2. Positioning the RCCA tool on the examination system (**third** video of the tool position mark),
3. Fast descent of the RCCA and ET data acquisition ,
4. Storage and validation of ET data,
5. Upwards movement at low speed and UT data acquisition,
6. Data validation and transfer on the analysis PC / 180° rotation of the RCCA,
7. Video image capture of the tool position mark,
8. ET on way down,
9. Data storage,
10. UT on way up,
11. Data validation and transfer on analysis PC,
12. RCCA change and analysis of the acquired data,
13. Examination of the next RCCA,

This fully automated cycle is part of the data acquisition software. To keep the NPP operator who pilots the RCCA handling tool permanently informed, messages on a LED screen are displayed describing actions like:

- Fast descent
- Low speed upwards movement
- 180° Rotation
- Next assembly identification

3.2 Calibration RCCA

The calibration RCCA is composed of 12 calibration rods adapted to the type of assembly to be inspected:

This calibration assembly enables:

- to perform a calibration for the OD measurement (probe trajectory) : this calibration is made on a solid rod section perfectly circular and of known diameter,
- to perform a calibration of the angular origin for each rotating UT probe, on an EDM notch
- to verify the accuracy of the axial encoder on two grooves 1mm deep, distant one from the other of 500 mm,
- to set the gain of the UT probes : this setting is carried out on the solid rod section ,
- to normalize the ET signal over the 20% groove.

In addition, this specific rod cluster has a function of validation.

Each rod of the calibration assembly includes:

A. an upper plug for UT calibration,

B. an uncoated tube length used for UT signal transfer,

C. an uncoated tube length with a notch for UT calibration and angular positioning of indications,

D. an uncoated tube length used for ET calibration,

This portion used for ET calibration contains AIC absorber and bears:

- an OD circumferential groove referred to as G20, (80% residual section),
- an OD circumferential groove G60 also used for the UT technique (40% residual section)
- a through wall notch
- a defect free portion between the grooves or between one groove and the notch for balancing.

Transfer signal

The ET and UT transfer blocks are in fact part of the calibration assembly; they are used for on-site revalidation of the system in the beginning of an inspection, (no degradation of qualification performances during on-site inspections).

UT transfer signals are obtained from V-shaped and lunule-shaped wear type degradations and swelling.

ET transfer signal is obtained from the through wall notch

4. Measurements performed

Both detection and characterisation are performed using one single data acquisition.

4.1 Measured magnitudes

In the case of wear, the magnitude to be measured is :

- the percentage of residual area (section) of the rod and the residual wall thickness.

For a through-clad penetration and for all units, the magnitude to be measured is:

- the residual thickness (it is smaller than or equal to a limit value when piercing occurs)
- the indication height in number of transversal profiles (pseudo-sections).

In the case of swelling, the magnitude to be measured is the outer diameter of the rod.

In the case of a crack, the magnitude to be measured is obtained using the ET measurement method : it is the amplitude of the Y component of the ET signal for the highest excitation frequency.

The rotation speed of the UT probes is controlled by the speed of the vertical movement of the handling tool. The system is designed for a nominal speed of the tool of 500 mm/min. with a maximum variation of ±125 mm/min. (25%). This enables to carry out UT data acquisition with the required examination step.

The rod is fully scanned by the UT transducers, on the way up, at the low speed of the handling tool, with a 3mm step helical path. The step is reduced to 1mm in the zone comprised between elevation 110 mm and the lower plug weld in order to meet the requirements of positioning accuracy of the Utility.

4.2 Characterisation

External profile measurement is performed by UT profilometry using an L0° transducer. For this measurement, calibration consists in scanning a stainless steel solid gage the diameter of which has been measured (metrology).

The control rod wall thickness is measured by spectrum analysis of the A-scan signal acquired. The same probe and the same transducer as for profilometry are used for this measurement.

Detection and characterization of wear and swelling are performed automatically on acquired data. When automatic analysis does not enable to interpret the results and when the difference between the rod smallest diameter and the largest one exceeds a predefined threshold, the diagnosis given by the system for the area concerned is “Manual analysis”. The analyst then manually centres the rod profile in order to obtain the characteristics of the degradation.

Spectrum analysis consists in detecting in the A-scan signal the signal generated by multiple reflections of the wave on the inner and outer wall of the rod, after suppression of the surface echo. Analysis of the frequency content of the A-scan, linked to a conversion curve established experimentally during the development of the process, enable to obtain the residual thickness of the examined wall. This technique does not require any calibration since the measurement result only depends on the A-scan analysed and the conversion curve. The implementation of this technique in France is an important technical innovation which enables to perform a direct measurement of defect features (residual thickness). Standard thickness measurement methods are actually not applicable in the range to be measured (1mm to 0.1mm).

4.3 Angular location of the defects

An angular encoder delivering 128 pulses per turn is used to obtain the angular position of the defects in the assembly referential.

4.4 Reference angular position

The reference angular position is obtained using a rotating target which cuts the transducer beam on each turn of the probes. Rotation of this target is synchronised with that of the UT probes thus enabling to define an absolute angular referential.

An example of the correspondence between UT profiles displayed with Neptune software and defect types is given on figure 3.

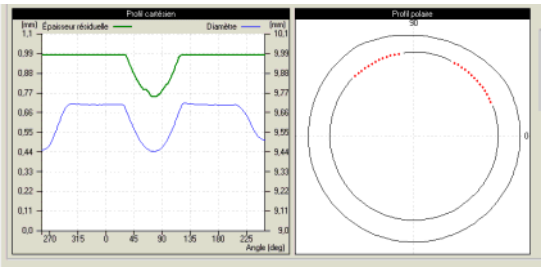
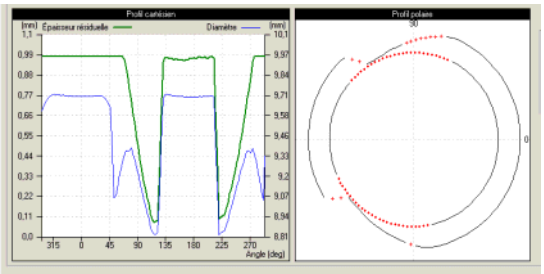
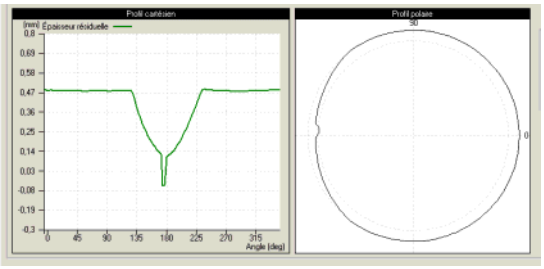
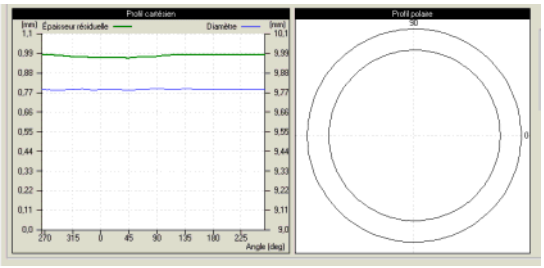
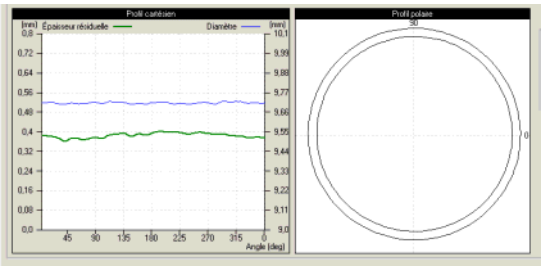
	Lunule-shaped wear
	V-shaped wear
	Through clad penetration
	Swelling
	Swelling + wear

Figure 3 : UT profile as displayed by NEPTUNE software and corresponding defect type

5. Qualified performances of JASPER system

Intercontrôle's process enables to ensure the detection of through-clad penetration by application of a dedicated recording threshold based upon the detection of a defect the residual thickness of which is nil (zero). Through-clad penetration is initiated by wear and

has a minimum height of 6 mm and a width of 0.5 mm. These dimensions are used for diagnosis but no characterisation is required.

5.1 Characterisation performances

Performances include basic performances and accuracy; performances are considered effective when 90% of measurements performed have the required accuracy.

5.1.1 Measurement of wear

Magnitude measured	Percentage of residual section	Minimum residual thickness
Measurement range	60 to 90 %	0.10 à 0.70 mm
Qualified accuracy	± 5 % of the section	± 0.03 mm

5.1.2 Measurement of swelling

Magnitude measured	Average diameter of circular section considered/
Measurement range	9.77 mm to 10.00 mm
Qualified accuracy	± 0.05 mm

Optional requirements

Optional requirements exist for two situations:

- when examining the portion of the bottom plug weld (0-6mm)
- In presence of cumulated degradation

5.1.3 Crack measurement

Each longitudinal crack open to the outer wall, with a height (or length) greater than or equal to 6 mm is identified.

5.2 Localisation performances

Localisation consists in determining the elevation associated to the detected indication. The precision depends on the position of defects on the clad.

Zone of the clad	Accuracy of localisation in elevation
[Lower plug weld ; 110 mm]	± 2 mm
[110mm ; upper plug weld]	± 10 mm

The technique proposed by Intercontrôle also enables to locate the defects on the rod circumference.

5.3 Repeatability and reproducibility of a measurement

The implemented technique enables repeatability of a measurement when repositioning the manipulator on an indication, without having changed a probe or an operating condition. The result is expected to fall in the required precision range.

Reproducibility is verified on the same indication after replacement of an ET or UT probe, or of the examination tool.

6. Validated performances

The qualification was obtained for the technique alone, then for the technique with the manipulator, and for the implementation of the technique.
The performances of the system fulfilled all Customer requirements. In addition:

- The system currently enables to perform the measurement of swelling at ± 0.02 mm, even in the case of cumulated degradation
- Characterisation of wear by measurement of the residual section is possible with ± 3 % accuracy when using manual analysis.
- The duration of the inspection of an RCCA is always the same whatever the number of detected indications.

Qualification will be definitively pronounced after an on-site implementation of the systems for two inspections. The first one is scheduled in May 2006.