ROTATING EXCITATION PROBE FOR INSPECTING PWR SG TUBES

H. Schepens*, M. Pigeon*, B. Benoist*, J. Reuchet**, and D.Boulanger**

*CEA/CEREM- Saclay, France
**IPSN/DES - Fontenay aux Roses, France

INTRODUCTION

The basic method for inspecting the soundness of steam generator tubes is multi-frequency eddy currents. The standard inspection of steam generator tubes of nuclear power reactors is now carried out using bobbin coil and Motorized Rotating Probe Coil (tube support plate, tube sheet and U-bend areas).

These probes have, however, a number of limitations:
for bobbin coil, its lack of sensitivity (by design) to circumferential defects,
for the MRPC, its low acquisition speed (mechanical rotation of a single point detector) which means that it cannot provide complete inspections of bundles liable to have outside circumferential cracks associated with localized corrosion.

As part of the improvement of Non Destructive Inspections performances, the CEA with the support of the Institut de Protection et de Sûreté Nucléaire (IPSN/DES) has evaluated the feasibility of an innovative multi-coil eddy currents probe for inspecting steam generator (SG) tubes of the 900 MW PWRs: the Rotating Excitation Probe (SET).

The objective with the SET is thus to have a single probe for routine and detailed inspections combining performance and speed, i.e.:
- overcome the low sensitivity for transverse (or circumferential) defects of the bobbin coil and increase the sensitivity of the MRPC,
- reach the speed of the present axial probe (500 mm/s).

Moreover, the tube surfaces must be covered without any dead zones for any relative probe/defect position.

This article gives the principles of this new probe. The first results allow its comparison with the MRPC (driving surface coil).

OBTAINED DEVELOPMENTS

There were 3 stages in our study:
1. Selection of the basic detector and transmission/reception configurations for ensuring the complete coverage of a tube surface.
2. Construction of a prototype for tube straight sections with tests using calibrated defects.
3. Construction of a second prototype for passage through bends (minimum radius 150 mm) and operating at two frequencies. Tests using calibrated and realistic defects.
This paper gives the results following the second stage.

SELECTION OF DETECTORS AND TRANSMISSION/RECEPTION CONFIGURATIONS

Due to the set objectives, the SET could not have mechanical rotary motion. A solution is thus to replace this motion by an electronic process. For this the probe must have several coils arranged on its circumference. A compromise between detection capability and ease of operation led us to select a cylindrical shape with two axially symmetric coils (separated transmit and receive modes) as coil unit.

To overcome the problem of resetting EC data as a function of variations in the probe's displacement speed, we decided to position the coil units on a single section of the probe. Due to the dimensions of these, the SET has only 16 coil units. Although such a configuration is favorable for circumferential defects, it is less sensitive for pitting or longitudinal defects between two detectors. To remedy this problem we have studied various possibilities of coupling the coils. These involve 1 to 4 adjacent coil units. We therefore selected three distinct Transmit/Receive configurations. These are shown in Figure 1, where for a given coil unit, T denotes the transmit mode is active and R the receive mode is active. These configurations (or channels) can be assembled on a mask with five adjacent detectors so that at a given time:
- an assembly of 4 out of 5 detectors is excited (one is not excited)
- three of these are simultaneously in the receive mode.

As an example, the response (from one of the EC components) of each configuration for a longitudinal through-wall slot 6-mm long is shown in Figure 2. The horizontal lines indicate the physical spacing between the coil units.

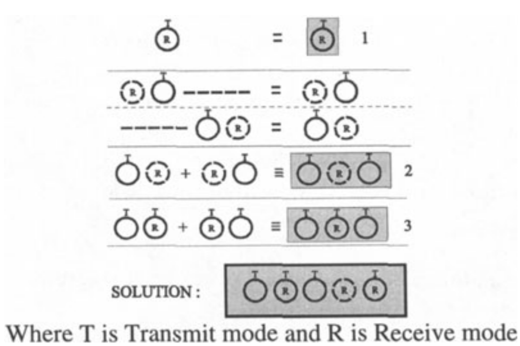


Figure 1. Simplification and response of different studied couplings.

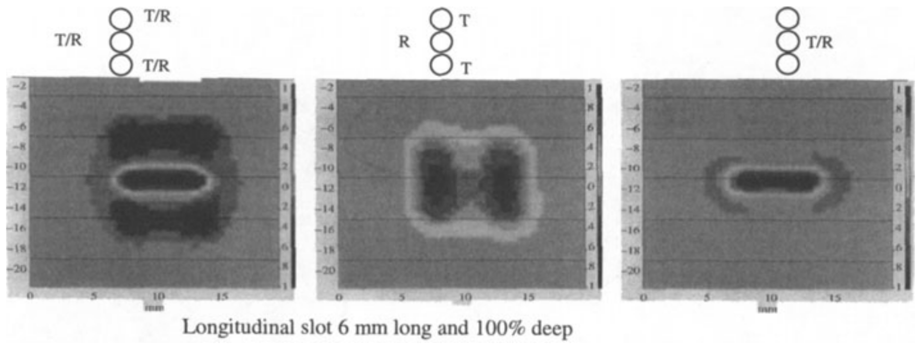


Figure 2. Influence zones of the three configurations on a longitudinal defect.

They are positioned randomly on the cartography and represent the path of the different coil units as they would be in the probe configuration. Thus, a longitudinal crack whose position and length are given by the T/R mode (provided that it passes directly below a detector) is always seen for the cases "T T/R T and "T R T" by at least two detectors.

OPERATION AND DESCRIPTION OF THE SET PROTOTYPE

To obtain complete information over all of the circumference of the probe, each coil unit (or at least its receiving section) must receive a signal in the three configurations (assembled on a mask). The switching sequence for the 16 coil units corresponding to a complete rotation of the excitation is shown in Figure 3. The four transmitters are powered together during the elemental time of a measuring step, and the three receiving signals (three channels) are stored simultaneously. Thus for one testing frequency, three matrices corresponding to the three modes ("T T/R T", "T/R", "T R T") are constructed.

The SET consists of a probe head automatically centered by brushes and a specific electronic switching assembly offset from the EC instrument. The probe head comprises 16 coil units (not in contact with the inner tube surface) mounted on a flexible support allowing this to be retracted if there is an obstacle and a module for coaxial connections between the windings and the electronics. The switching electronics controls the mask displacement from one coil unit to another. It operates with specific software, which ensures the synchronization of the measurements and adjustment of the EC parameters. This software is integrated in an industrial EC apparatus: Eddyscan30.X®.

FIRST RESULTS

The results given were obtained with the first prototype of the SET designed for 900 MW pressurized water reactor steam generator tubes (22.2 mm OD., 1.27 mm thick). The inspection frequency was 240 kHz and the spatial sampling 0.5 mm (the axial displacement speed is, as of now, limited to 200 mm/s by the associated data processing configuration). Comparison with MRPC (2.6-mm diameter absolute driving surface coil) was made at the same inspection frequency (F = 240 kHz). Signal acquisition was synchronized on the basis of a helical movement of 200 points per revolution with a 0.5-mm step.

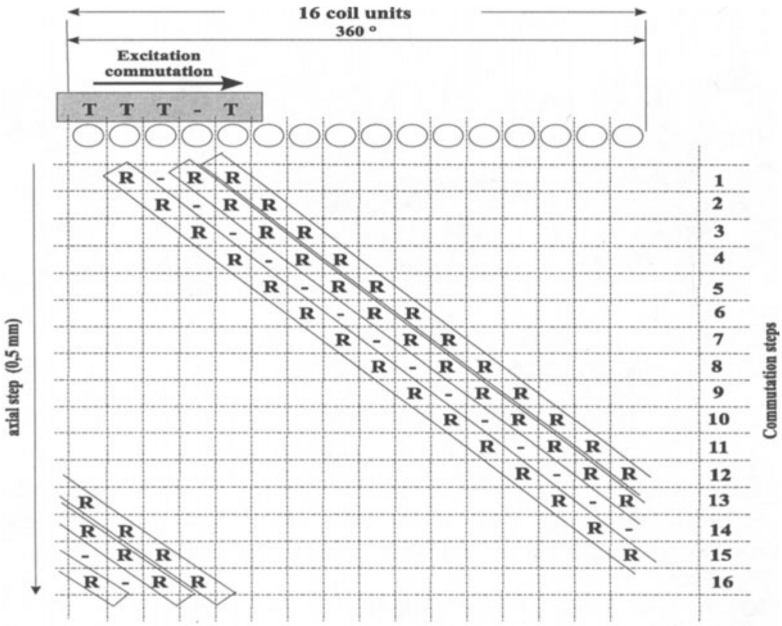


Figure 3. Mask switching sequence for 16 detector units.

The signals are shown as cartography where the vertical axis represents a tube cross section, the horizontal axis the tube axial direction and the level of gray the eddy currents signal module. For the SET, a cubic interpolation over 200 points is applied for smoothing the cartography and making its visual analysis equivalent to that of the MRPC.

The first application example is an OD longitudinal slot (10-mm long, 0.1-mm wide and depth 40% of tube thickness). To make a comparison, the signals from the two probes (for all the SET modes) are previously set at 1 volt on an OD longitudinal slot (10-mm long, 0.1 mm wide and 50% deep). The orientation of the defect is described equally well by the rotating contact probe (Figure 4.a) and the SET probe (Figure 5.a). The "T T/R T" mode is the most favorable for longitudinal defects. Extracting the Lissajous curves shows that the SET signal amplitude is higher than that of the MRPC (Figures 4.b and 5.b).

The second application example is a OD transverse slot (extended over 45° of the tube cross section, 0.1-mm wide and 40% deep). For a comparison, the signals from the two probes (for all the SET modes) were previously set at 1 volt on an OD transverse slot (10-mm long, 0.1 mm wide and 50% deep). The orientation of the defect is described equally well by the rotating contact probe (Figure 6.a) and the SET (Figure 7.a). The "T R T" mode is the most favorable for transverse defects. Extracting the Lissajous curves shows that the SET signal to noise ratio is higher than that of the MRPC (Figures 6.b and 7.b).

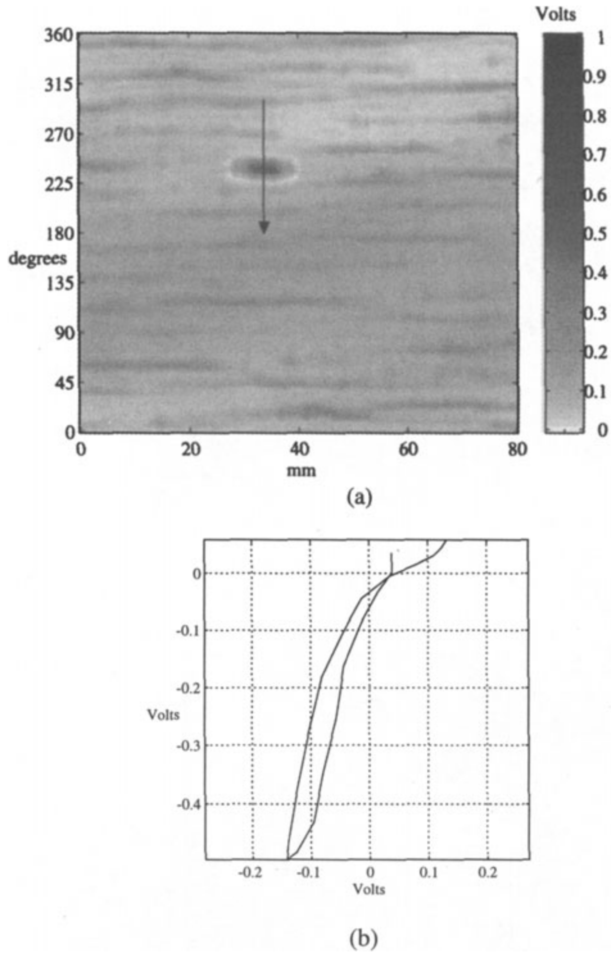
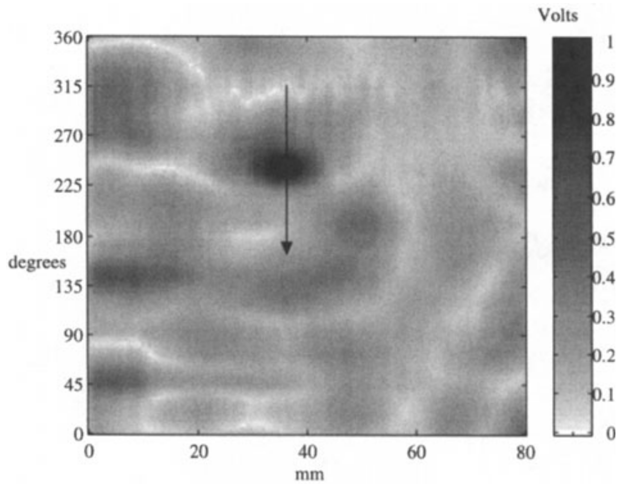
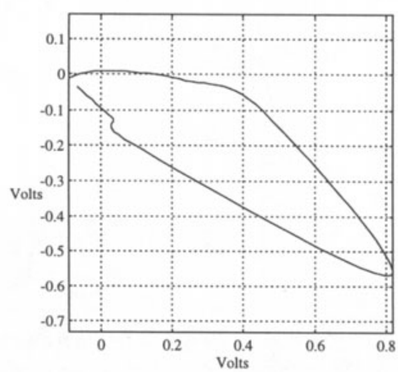


Figure 4. Inspection of the longitudinal slot (10-mm long, 0.1-mm wide, 40% depth) with the MRPC (2.6-mm diameter) (a) cartography of the eddy currents signal module (b) Lissajous figure extracted following the arrow.



(a)



(b)

Figure 5. Inspection of the longitudinal slot (10-mm long, 0.1-mm wide, 40% depth) with the SET in the "T T/R T" mode (a) cartography of the eddy currents signal module (b) Lissajous figure extracted following the arrow.

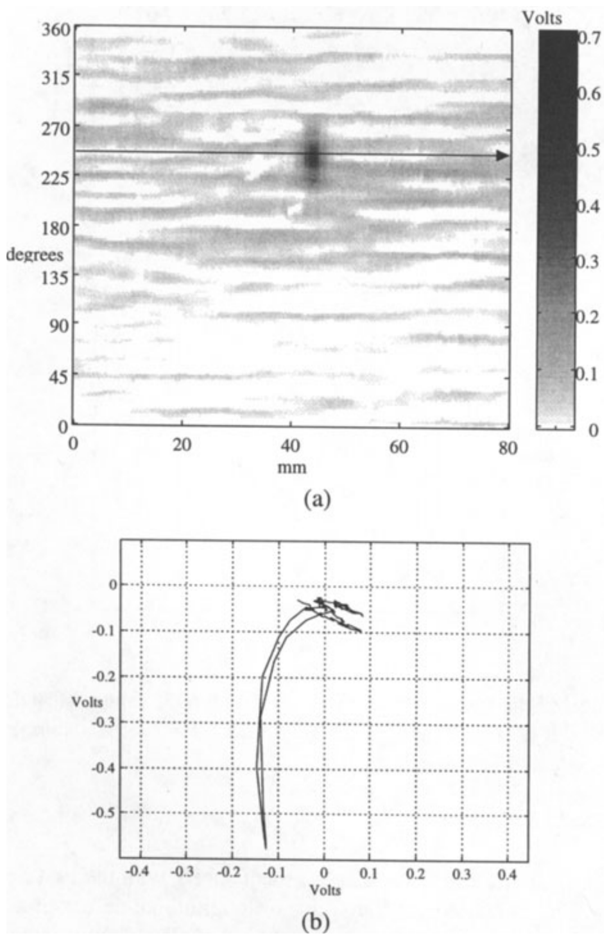
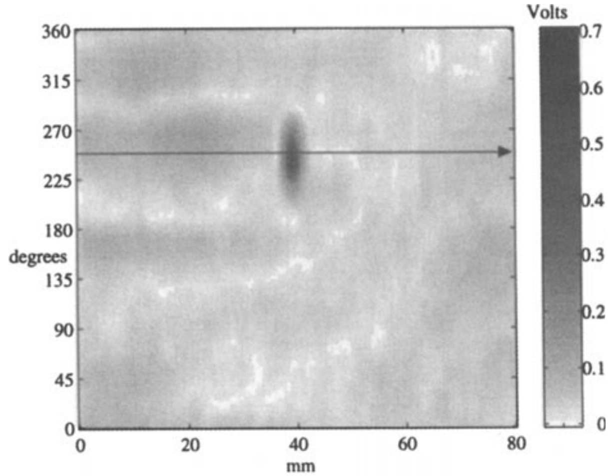
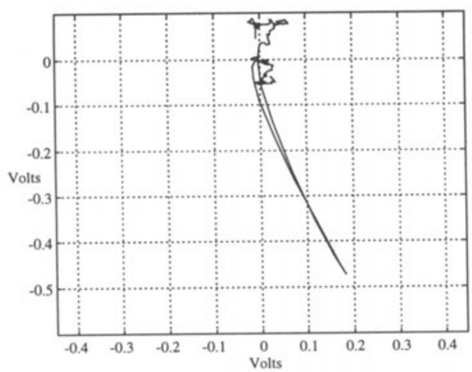


Figure 6. Inspection of the transversal slot (0.1-mm wide, 45° range, 40% depth) with the MRPC (2.6-mm diameter) at frequency, F, = of 240 kHz (a) cartography of the eddy currents signal module (b) Lissajous figure extracted following the arrow.



(a)



(b)

Figure 7. Inspection of the transverse slot (0.1-mm wide, 45° range, 40% depth) with the SET probe in the "T R T" mode (a) cartography of the eddy currents signal module (b) Lissajous figure extracted following the arrow

CONCLUSIONS

The results obtained at a 200 mm/s displacement speed with the first SET prototype are very encouraging. The orientation of transverse or longitudinal defects is accurately described. The multi-coil structure arranged on a section allows envisaging faster inspection of the SG tube (including U-bends) while improving defect detection. The three modes structure makes total covering of the tube circumference possible. We now have to evaluate the performances of the SET probe for a greater variety of defects, in particular, for its use in inspecting mock-ups with realistic cracks initiated.

Future developments include more powerful data processing facilities for both two-frequency inspections and an axial displacements of 500 mm/s.