FIELD TRIAL OF A FAST SINGLE-PASS TRANSMIT-RECEIVE PROBE DURING GENTILLY II STEAM GENERATOR TUBE INSPECTION

By

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ABSTRACT

A new generation of transmit-receive single-pass probes, denoted as C6 or X probe, was field-tested during the Gentilly II, 2000 steam generator tube inspection. This probe has a performance equivalent to rotating probes and can be used for tubesheet and full-length inspection at an inspection speed equivalent to that of bobbin probes.

Existing C3 transmit-receive probes have been demonstrated to be effective in detecting circumferential cracks. The C5 probe can detect both circumferential and axial cracks and volumetric defects but cannot discriminate between them. The C6 probe expands on the capabilities of both probes in a single probe head. It can simultaneously detect and discriminate between circumferential and axial cracks to satisfy different plugging criteria. It has excellent coverage, good defect detectability, and improved sizing and characterization. Probe data is displayed in C-scan format so that the amount of data to be analyzed is similar to rotating probes. The C6 probe will significantly decrease inspection time and the need for re-inspection and tube pulling.

This paper describes the advantages of the probe and demonstrates its capabilities employing signals from tube samples with calibration flaws and laboratory induced cracks. It shows the results from the field trial of the probe at Gentilly II and describes the instrumentation, hardware and software used for the inspection.

Introduction

Inspection of Steam Generator (SG) tubes has become a critical issue in CANDU Generating Stations. New findings of tight cracks at the defect prone tubesheet region, has prompted a need for higher defect detectability and 100% inspection, to provide assurance of fitness-for-service. This could result in extended outages and a decrease in capacity factor. Single-pass probes are required to satisfy the very tight inspection schedule (due to the relatively short outages of CANDU stations).

Since 1991, AECL has developed single-pass transmit-receive (T/R) array probes to address specific inspection needs. The C3 probe was specifically designed to detect circumferential cracks in Bruce A NGS. It proved effective in detecting cracks as shallow as 40% through-wall at deformed U-bend transitions and top-of-tubesheet. However, it has negligible sensitivity to axial cracks. The C4 probe can detect axial cracks and volumetric defects. It has been used successfully for detection of volumetric flaws (erosion-corrosion) at Pickering NGS. The C5 probe, used at Darlington and Gentilly II, can detect both circumferential and axial cracks but cannot discriminate between the two. Defect detection and sizing, especially in defect prone areas such as the tubesheet, support plates and U-bend regions, are required to assess the fitness for service of the SG. Information about flaw morphology and orientation is required to address operational integrity issues, i.e., risk of tube rupture, number of tubes at risk, consequential leakage and also to satisfy the different plugging criteria.

The C6 probe, named X probe for the American and European markets, is a fast single-pass probe with performance equivalent to rotating probes, for full-length inspection. New technology, developed by R/D Tech, has made it possible to combine C3 and C4 units in a single probe head. This permits better coverage, higher defect detectability, better sizing, and improved characterization capability with discrimination between axial and circumferential flaws in a single scan. It significantly decreases the need for re-inspection and tube pulling. The probe has been developed in collaboration with R/D Tech, an NDT instrument supplier and probe manufacturer, and with support from NEL of Japan, EDF of France, Hydro Quebec and COG, in demonstrating proof-of-principle of such a probe concept. Since the small defect signals are amplified at the probe end, this probe is more tolerant to cable deterioration; thus enabling longer probe life.

This new generation of T/R single-pass probes was first field tested during the Gentilly II 2000 SG tube inspection campaign, obtaining excellent results. In this paper we will describe the advantages of the probe, and demonstrate its capabilities employing signals from tube samples with calibration flaws and laboratory induced cracks. We will show the results from the field trial of the probe at Gentilly II. We will also describe the overall management approach taken for the inspection, using in house capabilities and a small number of contractors, which resulted in a very cost effective and timely operation.

Background information

Crack detection is one of the most challenging aspects of eddy current inspection of nuclear SG tubes. Large-scale inspection is performed using circumferentially wound bobbin probes. They are ineffective in detecting circumferential oriented cracks because the induced current in the tube wall circulates parallel to the coil windings and is inherently unaffected by the presence of such cracks. These probes are sensitive to axial cracks at straight tube sections; however, at defect-prone areas such as top of tubesheet and U-bend transition, the large signals generated by geometrical tube-wall distortions significantly reduce detectability [1, 2].

To address crack detection, the industry relies on surface riding rotating probes that can detect both axial and circumferential cracks. This is a very time consuming and costly process. Scanning speed is 2.5 mm/sec compared to array probes that can scan tubes at 450 mm/sec. These probes are usually spring loaded to minimize lift-off, which makes them prone to failure. This is especially evident in CANDU reactors where the presence of internal magnetite deposits reduces probe life significantly.

T/R array probes designed by AECL have been used successfully since 1991 to inspect CANDU SG, addressing specific inspection needs. These probes take advantage of the superior properties of T/R technology compared to impedance probe technology. They have a five to ten-fold improvement in signal-to-noise ratio in presence of lift-off caused by geometrical tube distortion such as U-bend deformations or tubesheet transition [3, 4]. This makes it unnecessary to have moving parts, increasing probe reliability.

Directional properties and probe design

Since T/R probes have directional properties, being sensitive primarily to defects in-line with the T/R coil pairs, the probe design can be optimized to maximize response for different crack orientation [3, 4]. The area of sensitivity of a T/R unit is illustrated by the computer simulation results shown in Figure 1. The probe maximum response corresponds to variations in the induced magnetic field in the region between the transmit and receive coils. Thus, the C3

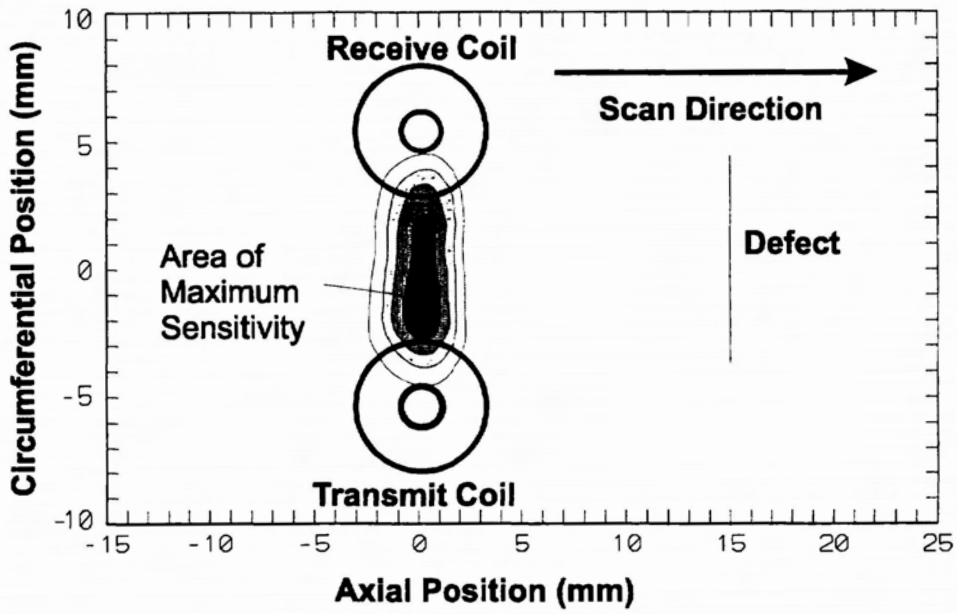


Figure 1: Computer simulation illustrating areas of sensitivity and directional properties of T/R probes.

probe has been designed to be primarily sensitive to circumferential cracks whereas the C4 is sensitive to axial cracks, and both probes have very good sensitivity to volumetric flaws.

The C6 probe embodies C3 and C4 units in a single probe head. This is made feasible by including microelectronics at the probe end. The microelectronics permit the use of more coils while simplifying cable requirements. Figure 2 shows a schematic of the probe's coil arrangement. The probe for 13 mm diameter, Incoloy 800 tubing comprises four rows of 12 coils that operate alternatively as C3 probe units and C4 probe units allowing simultaneous detection of circumferential and axial cracks as well as volumetric flaws. This single-pass probe has capabilities equivalent to rotating probes, but can scan the tubes at 450 mm/sec compared to 2.5 mm/sec for rotating probes.

Display of Data

Similarly to other array probes, the C6 probe generates large amounts of data. Analyzing the data generated by each of the 72 individual T/R units operating at four frequencies would be very time-consuming and complicated. To simplify the process, and make signal analysis user-friendly, the data are displayed in C-scan format, reducing the number of data channels to be analyzed, while retaining all the original data. The R/D Tech Multiview software can be configured to generate C-scans for each mode of detection combining all T/R units in a single row. Thus, the final set-up consists of two C-scans for circumferential crack detection mode and of two C-scans for axial crack detection mode at each operating frequency. These C-scans can be later combined to generate differential channels and multi-frequency channels, to aid in detection and characterization of defects.

Figures 3a and 3b show C-scan and isometric C-scan displays of calibration tube data for each mode of detection at 250 kHz, illustrating the probe directional properties. The C3 detects only the circumferential ID and OD EDM notches contained in the calibration tube (Figure 3a) whereas the C4 detects only the axial ID and OD EDM notches (Figure 3b). The images also show that the C3 and the C4 modes are both capable of detecting volumetric flaws (flat bottom holes and concentric grooves).

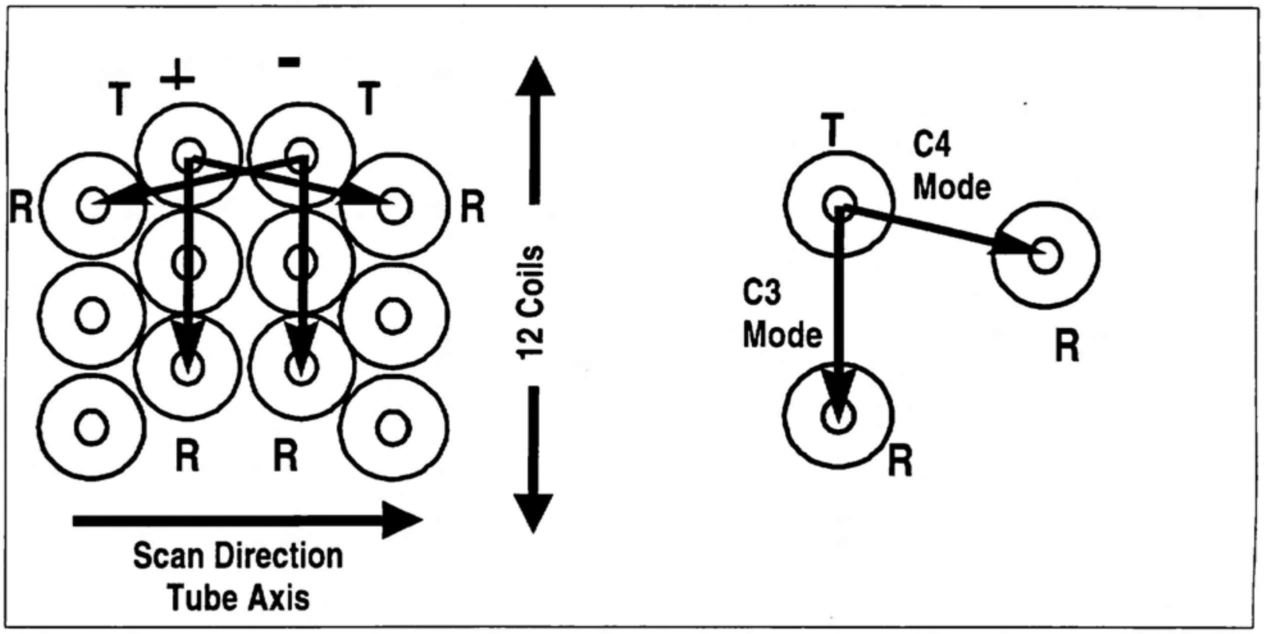


Figure 2: C6 probe coil schematics, for 13 mm diameter, Incoloy 800 tubing, showing C3 and C4 coil pairs. The C3 units are primarily sensitive to circumferential oriented cracks and the C4 units are primarily sensitive to axially oriented cracks.

Laboratory Tests

The probe performance was initially tested in the laboratory with very good results, meeting design requirements of detection, coverage, and resolution capabilities. The ability of the probe to distinguish between circumferential and axial cracks, and volumetric defects, was demonstrated in tests with machined flaws (EDM notches), and tubes with real axial and circumferential stress corrosion cracks. Figures 4 a and b, and Figures 4 c and d provide the results from two tubes containing, respectively, laboratory-induced axial and circumferential SCC approximately 30% deep. These figures show that the probe can clearly distinguish between axially and circumferentially oriented flaws.

The probe is able to cover 100% of the tube circumference with 15 to 30% variation in signal amplitude from small flaws. Spatial resolution of the probe was measured using tubes containing adjacent small diameter holes with increasing spacing. The results showed a spatial resolution of 40 to 50^0 around the tube circumference and 4 to 6 mm along the tube axis [5].

Field results

The probe provided excellent field results at Gentilly II, while achieving high inspection speed and clear imaging to help define defect morphology. The tubes did not show any signs of cracking; however, the inspection with bobbin probe had detected fretting-wear at the U-bend staggered scallop-bars in a small number of tubes. Some of these tubes were re-inspected with the C6 probe. Figure 5 shows signals from fretting-wear scars located under the staggered scallop bars. The C-scan image indicates that the degradation is occurring at the edge of the scallop bars at this location. Also, the weaker signal from one of the scallop bar sections infers a larger gap between this section and the tube wall compared to the adjacent one.

The ability of the probe to map the circumferential extent of the flaws was an important tool that helped characterize the degradation mechanisms. The analysis team also used the C6 probe data to help sizing these flaws.

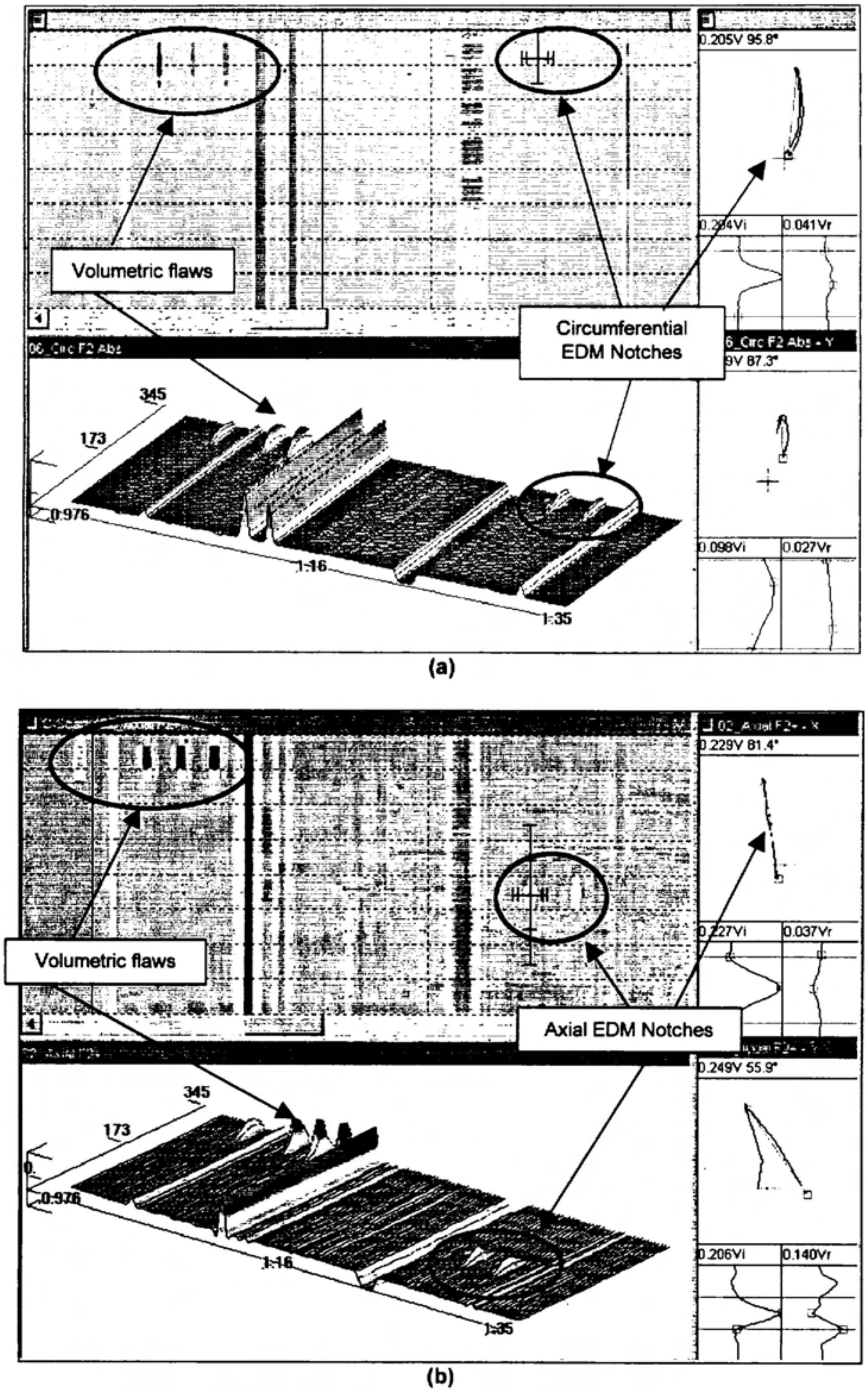
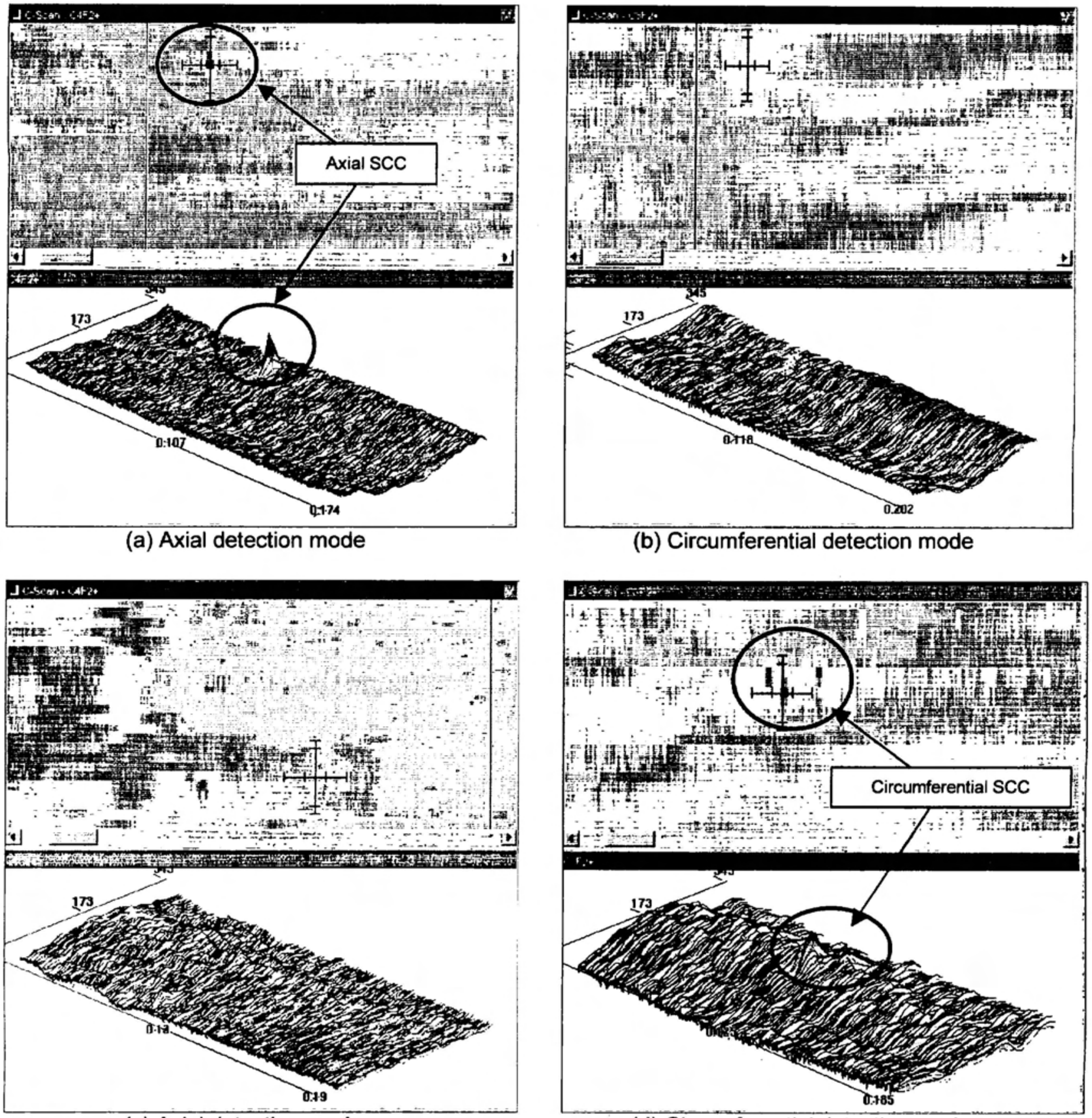


Figure 3: C-scan and isometric C-scan displays of calibration tube data for each mode of detection, illustrating the probe directional properties. The images show that the C3 and the C4 modes are both capable of detecting volumetric flaws (flat bottom holes and concentric grooves).

a) The C3 detects only the circumferential ID and OD EDM notches
b) The C4 detects only the axial ID and OD EDM notches.



(a) Axial detection mode

(b) Circumferential detection mode

(c) Axial detection mode

(d) Circumferential detection mode

Figure 4: Signals from two tubes containing laboratory-induced SCC approximately 30% deep. They show that the probe can clearly distinguish between axially and circumferentially oriented flaws.

a) and b) The axial crack is detected only by the C4 probe (axial detection mode)

c) and d) The circumferential crack is detected only by the C3 probe (circumferential detection mode).

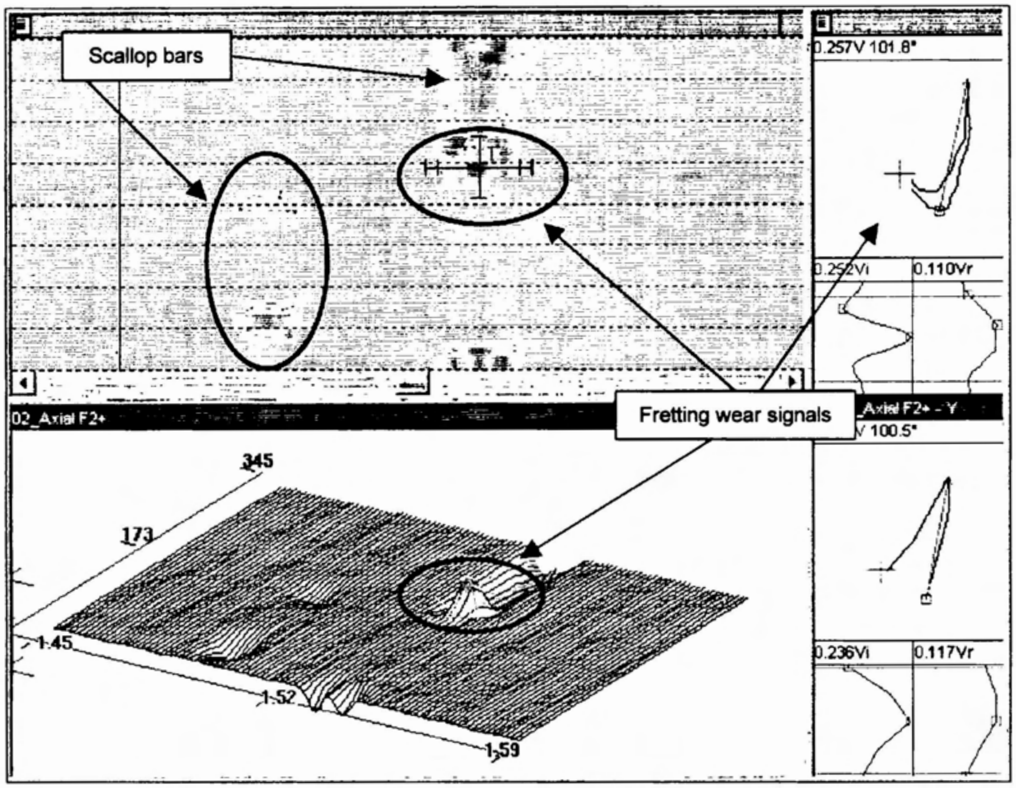
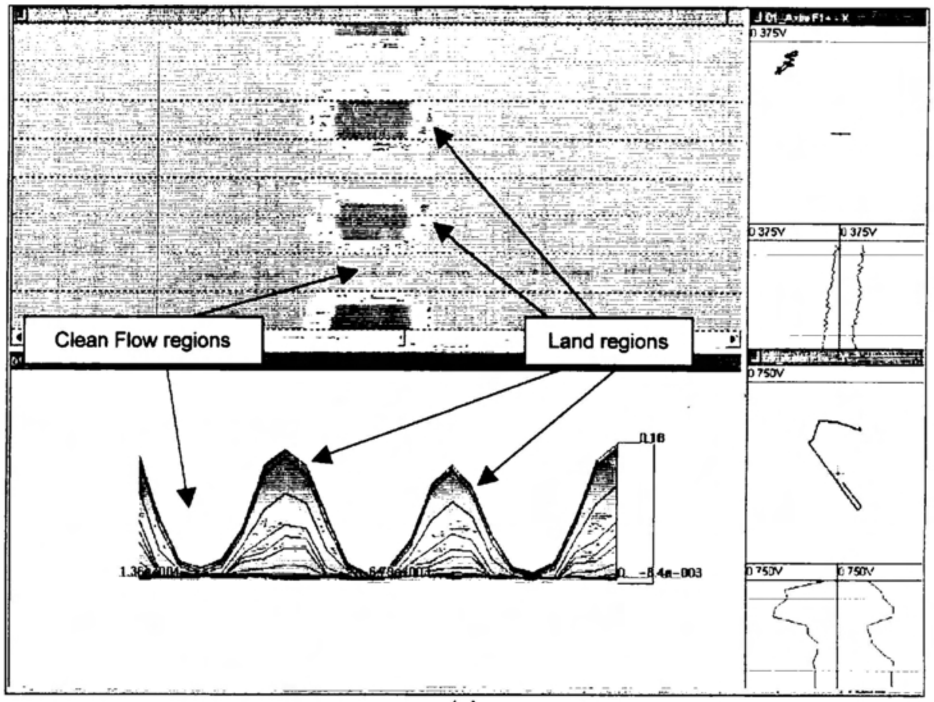


Figure 5: Field signals from fretting wear scars located under the Gentilly II staggered scallop bars. The C-scan image indicates that the degradation is occurring at the edge of the scallop bars at this location. Also, the weaker signal from one of the scallop bars infers a larger gap between this section and the tube wall compared to the adjacent one.

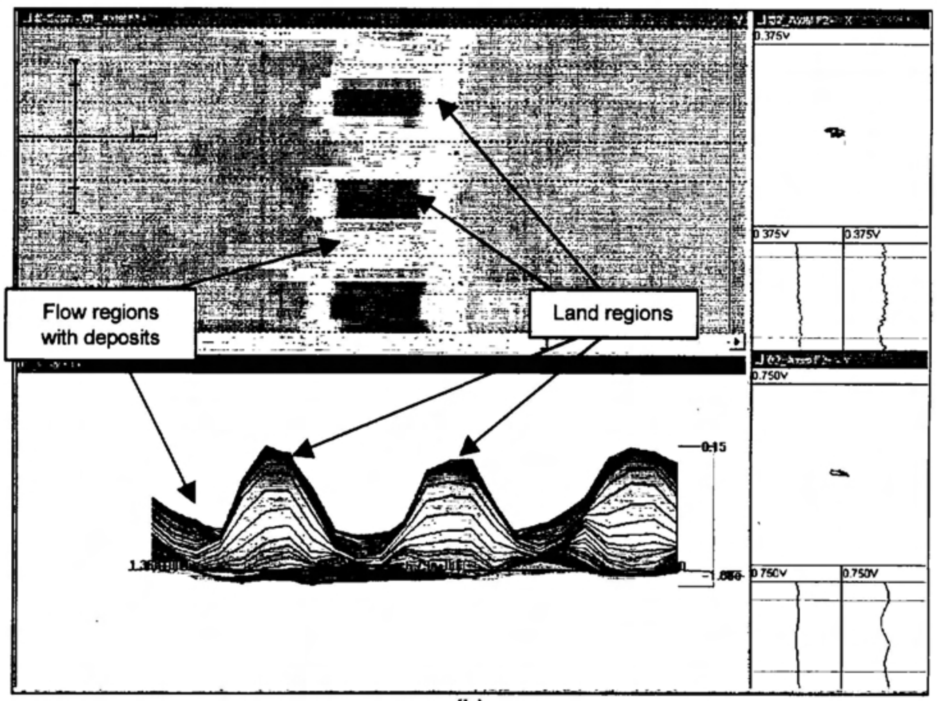
Signals at a lower frequency provided clear and quick imaging of external deposits at the broach plate support as shown in Figure 6.

These results demonstrate the potential value of the probe as a single-pass inspection tool for CANDU utilities. The ability of the probe to "map" artifacts, added to flaw detection and characterization capability, results in a wide range of possibilities for probe application within operating and new CANDU SGs.

From the mechanical point of view, the probe easily negotiated large U-bends (941 mm radius) with the aid of the air assisted probe drive manufactured by R/D Tech. Additional tests on smaller radius U-bends were not attempted.



(a)



(b)

Figure 6: Field signals from Gentilly II broach plates at 70 kHz. The isometric C-scans give a clear imaging of deposits at the flow regions under broach plates.

a) Clean broach plate. The signals from the flow regions return to the base line.
b) Broach plate with magnetite deposits. Magnetite deposits were detected at the flow regions.

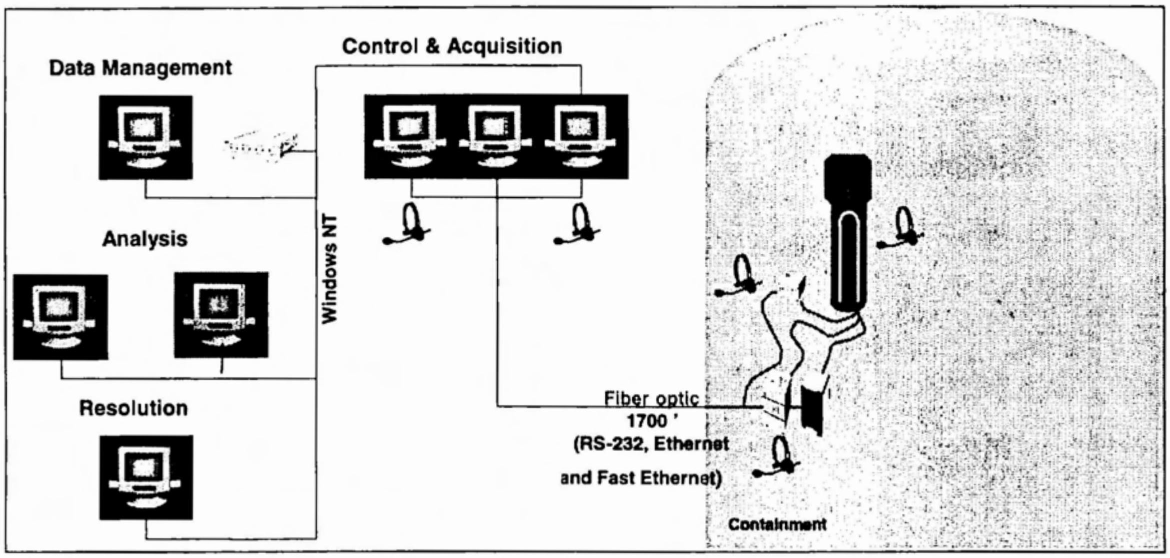


Figure 7: Gentilly II eddy current inspection set-up

Inspection implementation

SG inspections in CANDU nuclear power plants are frequently in the critical path due to the short outage time. Therefore inspection time and cost were two major determining factors in deciding the inspection management approach.

This was the first time a full-scale inspection was performed at Gentilly II, since only a small number of tubes had been inspected during previous outages. The complete operation was in-house managed. Hydro-Québec personnel operated the acquisition equipment and related software with these additional contractors: Logitest, Canspec and Midatech. CGSB level II and QDA level III and II analysts from AECL, MoreTech and Taratech and B&W performed Data Analysis. They were divided in two twelve-hour shifts. Each shift consisted of one coordinator, three data analysts, four equipment operators and two green badges. Figure 7 describes the inspection organization chart.

This was a fully automated inspection using commercially available instrumentation, software and hardware, as well as in-house developed software:

- Two R/D Tech Probe Pushers with HQ control & software,
- Two "Finger walker" robots with HQ control & software,
- One R/D Tech TC6700 eddy current instrument,
- One TC7700 eddy current instrument for the C6-Probe and
- Multiview software for acquisition and analysis.

Only nine R/D Tech bobbin probes were required to complete the general inspection. One R/D Tech C5 probe was used for defect characterization and one C6 probe for field trial on about 50 tubes.

This was a very successful undertaking. It was completed ahead of schedule requiring only five days to inspect 1800 (51%) tubes in SG 1 and four days to inspect 1800 (51%) tubes in SG 3. The nine days included full length scans as well as equipment installation and removal. The initial time estimate was ten days.

Self-management resulted in significant cost savings. The experience gained and the lessons learned by the team members will help improve inspection capabilities and efficiency for future inspections.

Summary of inspection results

- No tubes were plugged
- No significant indications detected
- 100 tubes characterized with C6 probe and C5 Probe
- Some small fretting was detected at U-Bend <20% deep
- Nine bobbins probes used to inspect 50% of two SG
- After one year of operation following primary side cleaning, no significant fouling on the tube ID

Summary/Conclusions

The development and field trials of the first C6 probe prototypes (also known as X probe) for 5/8" Incoloy 800 tubing at Gentilly II were a success.

The C6-probe, as a single-pass array probe, was shown to have with similar capabilities to rotating probes. Probe performance, tested in the laboratory, met design requirements of coverage, resolution, and detection capabilities.

It operates at a scanning speed comparable to that of bobbin probes, reducing outage time.

Simultaneous detection and discrimination of circumferential and axial cracks in addition to defect sizing capabilities will reduce the need for re-inspection and tube pulling.

Signal analysis is easy and reliable with the use of C-scan and isometric C-scan, which is similar to rotating probe analysis methods.

Acknowledgments

The authors are indebted to the IMD Branch personnel and students for their assistance in probe development and collection of data described in this paper.

The authors also wish to thank to the computers and networking personnel and the acquisition and analysis personnel for their hard work and dedication during the Gentilly II inspection.

Special thanks to:

Gentilly II, IREQ, RD *Tech and* Cybectec personnel for the development of the control systems.

R/D Tech for manufacturing the probe and the development of hardware and software essential for the operation of the probe.

The participants in the project for their support: AECL, NEL, Hydro Québec, EDF, and Ontario Power Generation.

EPRI for their interest and support.

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