ULTRASONIC INSPECTION EXPERIENCE OF STEAM GENERATOR TUBES AT ONTARIO HYDRO AND THE TRUSTIE INSPECTION SYSTEM

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ABSTRACT

Ontario Hydro have been using ultrasonic test (UT) technique to inspect steam generator (SG) tubes since 1993. The UT technique has higher sensitivity in detecting flaws in SG tubes and can characterize the flaws with higher accuracy. Although an outside contractor was used initially, Ontario Hydro has been using a self-developed system since 1995. The TRUSTIE system (Tiny Rotating UltraSonic Tube Inspection Equipment) was developed by Ontario Hydro Technologies specifically for 12.7 mm outside diameter (OD) tubes, and later expanded to larger tubes. To date TRUSTIE has been used in all of Ontario Hydro's nuclear generating stations inspecting for flaws such as pitting, denting, and cracks at top-of-tubesheet to the U-bend region.

INTRODUCTION

Ontario Hydro has 4 nuclear generating stations (NGS), Pickering, Bruce A, Bruce B and Darlington, with a total of 20 reactors/units (19 of these are operating as of December 1997). Due to unique design, especially in Pickering NGS, there is comparably a large number of SGs and SG tubes. Since the whole SG tube system is one of the components that upholds the pressure boundary of the primary heat transport system (PHT), its integrity is of vital importance to the NGSs. Furthermore, since the CANDU reactor's PHT system is made up of heavy water, the integrity of the SG tubes is also an economic concern for Ontario Hydro.

To reassure ourselves that these SG tubes are fit for service, Ontario Hydro conducts major inspection campaigns every year. These inspections are done periodically under the CSA standard, our own in-service-inspection (ISI) programs, or due to discovery of leaks. The technique used for high volume inspection production is eddy current test (ECT). By applying advanced techniques, such as the Cecco series of probes and other advanced probes, ECT can detect and measure most flaws in SG tubes. However, in the situation where the flaws are below the inspection threshold of ECT, or when there are other existing factors affecting the performance of ECT, a more sensitive and better method is needed. UT has been proven to be able to detect and measure flaws beyond the threshold of ECT, and it is insensitive to factors such as permeability and conductivity. The TRUSTIE system used by Ontario Hydro employs rotating probes which, when combined with an axial motion, inspects tubes in a helical manner. The speed of inspection is much lower than ECT. Therefore, UT is used in Ontario Hydro to complement ECT, not to replace it.

THE VAST NUMBER OF SG TUBES IN ONTARIO HYDRO NUCLEAR

The following table summarizes the key properties in Ontario Hydro Nuclear's SGs :

	PNGS	**BNGS-A & BNGS-B**	**DNGS**
number of units	8	8	4
SGs per unit	12	8	4
Tubes per SG	2600	4200	4663
Tube material	Monel 400	Inconel 600	Incoloy 800
OD (mm)	12.7	13.0	15.9
Wall thickness (mm)	1.2	1.1	1.1
Earliest operation	July 1971	September 1977	October 1990
Per unit rating	540MWe	910MWe	935MWe

The total number of SGs is 176 and the total number of tubes is 593,008.

DEGRADATION MECHANISMS

ECT and UT have encountered these degradation mechanisms in Ontario Hydro's SGs (refer to presentation slide #3) :

- Tube fretting at U-bend support bars
- High cycle fatigue crack at top tube support plate (TSP) and U-bend
- OD stress corrosion cracking (SCC) at top TSP and U-bend
- Fouling of tube surface
- Pitting at top-of-tubesheet (TTS) and lower TSPs regions
- Debris & loose parts damage
- IGA and primary water SCC (PWSCC)

UT INSPECTION STRATEGY

The main purpose for using UT is to supplement and complement ECT during SG tube inspections. UT was used in pitting detection and sizing, crack detection, profilometry and deformation measurement. UT is recommended as one of the verification methods in Bruce NGS's SG ISI program. Presently, in Ontario Hydro Nuclear, almost all periodic ECT inspections are followed by UT of about 120 tubes per SG. These UT inspections normally include 75 tubes tested with normal beam and 45 tested with shear wave. This gives a good overall inspection for both pitting and cracks.

In addition to flaw detection UT was used in the verification of quality during the trial sleeving installation in Pickering NGS's SG tubes. Normal beam UT was used to verify the thickness and completeness of the sleeving process.

INSPECTION CAMPAIGNS (UP TO THE END OF 1997)

Date	Performed at	Inspect for - scope	# of tubes
April/May 1993	PNGS unit 6	Trial run - 2 tubes	2
September 1993	PNGS unit 8	Sleeving trial - 12 tubes, ***used Flexivera arm from this point***	12
November/December 1993	PNGS unit 1	Pitting -12 tubes Denting - 7 tubes	19
January/February 1994	PNGS unit 1	Sleeving trial - 6 tubes Pitting - 125 tubes, ***used Zetec SM-13 arm from this point***	131
April 1994	PNGS unit 5	Circumferencial cracks - 76 tubes	76
May 1994	PNGS unit 5	Sleeving installation - 48 tubes, 17 of them in SG	48
August 1994	PNGS unit 1	Top roll joint location detection - 10 tubes Pit growth monitoring - 3 tubes Circumferential cracks - 16 tubes	29
November/December 1994	PNGS unit 1	Pitting -30 tubes Denting - 25 tubes, 1 at U-bend	55
April 1995	PNGS unit 5	Sleeve re-inspection - 14 tubes	14
May 1995	BNGS-B unit 6	Micropits - 59 tubes	59
	BNGS-A unit 4	Pits/deposits - 106 tubes Dents - 6 tubes	112
	DNGS unit 4	TTS - 18 tubes	18
September 1995	BNGS-B unit 8	TTS micropits - 61 tubes	61
October/December 1995	BNGS-A unit 1	U-bend cracks -7 tubes TTS - 90 tubes 1st TSP pits & circ.cracks - 20 tubes ***used Zetec SM-23 arm from this point***	117
May 1996	BNGS-A unit 3	TTS pitting - 205 tubes TTS cracks - 90 tubes	295
May 1996	DNGS unit 1	TSP H01-H07 fretting - 92 tubes	92
October 1996	BNGS-B unit 5	TTS micropits - 80 tubes	80
January 1997	PNGS unit 8	TSP H01-H09 erosion/corrosion - 40 tubes	40
April 1997	BNGS-A unit 1	TTS pitting - 140 tubes TTS cracks - 90 tubes	230
June 1997	PNGS unit 4	TSP H01-H09 frets/ wall-loss - 38 tubes	38
July 1997	BNGS-B unit 6	Pre-heater PH1 for fretting in U-bend - 24 tubes	24
December 1997	BNGS-B unit 6	Micropits and IGA at TTS - 141 tubes	141
December 1997	PNGS unit 7	ECT indication confirmation - 50	50
		Total number of tubes inspected :	**1,743**

THE TRUSTIE SYSTEM

The TRUSTIE system was developed by Ontario Hydro Technologies (OHT) initially to inspect Pickering NGS SG tubes (refer to presentation slide #9 and #10). The probe size also fit the Bruce A and B SG tubes with minor modifications. Later, probes were built for the larger Darlington NGS SG tubes.

Features

TRUSTIE is a computer controlled, remotely operated system. Under the control of a Pentium grade computer running a custom written software (refer to presentation slide #11), the operator can control probe drive motion, probe rotation, and acquire and analyze data. Probe positioning is provided by an SG tube inspection manipulator much the same way as in ECT. The features of the TRUSTIE system is listed below:

- External rotary drive/drive-shaft
- Control computer operates under MicroSoft Windows 95
- Tube ID from 8.0 mm (0.310") to 33 mm (1.3")
- Tube lengths up to 12.2 m (50')
- UT inspection frequencies from 5 to 25 MHz
- rotation speeds up to 1000 rpm
- typical data collection speeds:
  - 600 rpm form 4-gate C-scans
  - 600 rpm for full waveform scans (at 0.2 mm by 1.5 degree resolution)
- U-bend inspection to 406 mm (16") radius for 12.7 mm (0.5") OD tubes
- remote operation to 183 m (600')

UT capabilities

- Probe types :
  - normal beam (wall thickness/ profilometry)
  - axial facing shear wave (circumferential cracking+ ID profilometry)
  - multiple mode combination (normal beam + circ. and axial shear waves)
  - others
- Analysis methods:
  - A, B, C and waveform scans
  - line plots, colour plots, isometrics
  - echodynamics
  - integrated signal processing (e.g. filtering, spectral analysis)

Established flaw detection and measurement capabilities

Several exercises were conducted to verify the flaw detection capability and flaw measurement accuracy. These exercises include :

- Removal of inspected tubes from the SG and examine them in metallurgy laboratory. UT reported flaws were compared to actual measurement results
- Scanning flaw samples precisely made by electronic discharge machining (EDM)
- Scanning removed tubes in metallurgy laboratory with known flaws

From these exercises, the capabilities of TRUSTIE has been established as follows :

- Pitting and general wall-loss detection and measurement to 5% through the wall (TTW)
- Micro pit detection threshold is 0.2-0.3 mm surface area and 10% TTW

Stress corrosion cracking (SCC) inspection capabilities

A probability of detection (PoD) exercise for TRUSTIE was conducted specifically on SCC. Over 70 SCC specimens were produced in metallurgy laboratories. The SCCs were classified into primary cracks and secondary cracks. Primary cracks were those equal to or greater than 55% TTW, and secondary cracks were those smaller than 55% TTW. Secondary cracks were basically used to establish low range PoD. The TRUSTIE system scanned all specimens and the results were compared to destructive testing findings. About half of the specimens were destructively examined.

The PoD exercise showed that all cracks were detected and correctly identified. Statistic evaluation indicated a 90% PoD for cracks 30% or more TTW (refer to presentation slide #14).

THE FUTURE (CAPABILITIES UNDER DEVELOPMENT)

While the TRUSTIE system has been performing its designed tasks satisfactorily, there are a few areas that can benefit from some improvement. The speed of inspection is certainly one area where there is much room for improvement. Other areas will enhance the smoothness of operation, expand the application of the system and migrate the software platform to a faster operating system. The following is a list of planned developments :

- Rotating speeds increased to up to 200 rpm
- Multiple element probes, eliminating rotation
- Replaceable probe heads for ECT, laser profilometry or other probes
- Network remote operation to eliminate multiple-cable penetration through the reactor building wall
- Scaled up probes for larger diameter tubes or pipes
- Smaller, portable version for non-remote and smaller scale inspections
- 32-bit Windows NT operating platform