CURRENT & FUTURE ULTRASONIC INSPECTION FOR CANDU SG TUBES

Z. Chen[1], K. Chan[1], and
J. Huggins[2] , T. Malkiewicz[2]

[1,] Kinectrics Inc., Toronto, Ontario, Canada
[2,] Ontario Power Generation, Ontario, Canada

Abstract

Ultrasonic inspection (UT) plays an important role in CANDU Steam Generator (SG) life cycle management. Ultrasonic inspections offer a superior capability that can assess the severity of flaws in SG tubes and accurately monitor their growth. Ultrasonic inspections with TRUSTIE™ * has proven to be a valuable tool for verifying and providing detailed characterization of flaws detected by Eddy current (ET) techniques. On going developments of the TRUSTIE ultrasonic inspection technology continue to produce advanced tools for SG tube inspection. This presentation will provide the current state and future expectations (or developments) for ultrasonic inspections of SG tubes in CANDU nuclear power plants.

* TRUSTIE™: Tiny Rotating UltraSonic Tube Inspection Equipment

1. Introduction

Steam Generator tube degradation due to metallurgical and mechanical conditions has led to extensive in-service inspection for timely monitoring. The eddy current method has long been the industry standard for inspecting steam generator tubes for many years. Ultrasonic inspection complements eddy current inspections by providing additional evaluation and characterization of the morphology, depth, distribution and location of defects. Certainly ultrasonics provides a critical tool with which to assess the severity and monitor the growth of flaws in SG tubes. It also supports the fitness for service assessments of steam generator tubing.

Advanced ultrasonic inspection techniques associated with TRUSTIE have been established for the evaluation of various steam generator tube conditions, including pits, frets, dents, stress corrosion cracks, and tube deformation for many CANDU steam generators since its pilot test in 1994 for qualifying electrosleeves. UT has primarily been utilized as a verification technique for ET tube inspection, giving more accurate depth sizing and flaw discrimination.

Ontario Power Generation (OPG) and Kinectrics have been working together to implement TRUSTIE technology for many years. The joint efforts are currently focusing on the development and implementation of specific ultrasonic techniques to address degradation issues and to meet specific inspection needs for CANDU SG tubing. Increasing demand for ultrasonic examination of SG tubes due to the component aging has led to the development of new system components for improving reliability and productivity of TRUSTIE. New innovations such as multiple element probes, servo drive systems, and fibre-optic network connection enables high-speed data acquisition and networking to meet parallel campaigns and tight outage schedules. Some of the development work to improve the probe technology and data processing techniques for inspection has been sponsored by CANDU Owners Group (COG) programs.

The objectives of these concentrated efforts were to develop fast and reliable steam generator UT inspection capabilities for flaw characterization and fitness-for-service assessment of SG tubes. This paper provides an overview of the current state of the TRUSTIE system and future developments for ultrasonic inspections of SG tubes in CANDU nuclear power plants.

2. Equipment Technology Overview

The TRUSTIE system is based on a rotating flexible driveshaft with a replaceable ultrasonic mirror probe attached. A manipulating arm such as the Zetec SM-23 is used for delivery of the probe to the selected SG tube. The control of the UT system and the acquisition of the ultrasonic data are performed remotely using Winspect, a 32-bit Windows-based data acquisition and motion control program. Figure 1 shows a TRUSTIE system.

Figure 1. TRUSTIE System

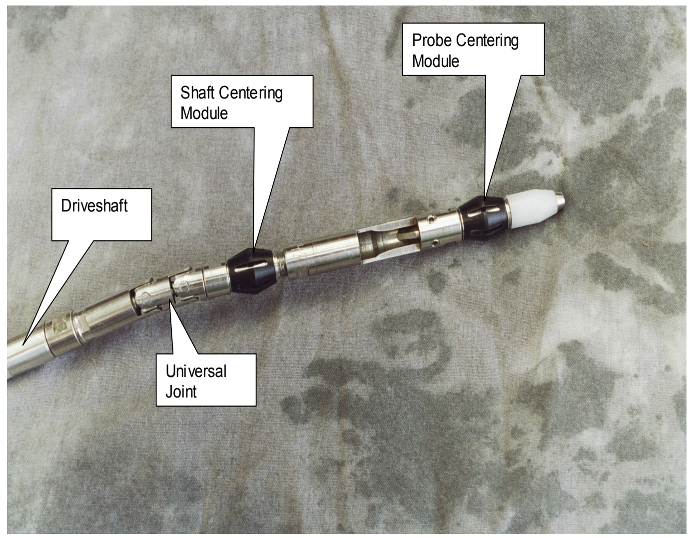

Figure 2. Example TRUSTIE Probe

A production TRUSTIE system usually requires two computers, one for data acquisition and one for data analysis. The computers are networked to a local server through a fast hub in order to save and retrieve large volumes of data quickly. The acquisition computer and Winspect software control the UT scans in high resolution using both axial and rotary motions. The user can set specific motion control details to suit the tubing diameter, length of scan, type of scan and resolution required.

The driveshaft provides the mechanical and electrical connection between probes and drive systems. As shown in Figure 2, centering modules keep the probe centered in the tube and provides a bearing for the rotary motion. The single element UT probe is designed to accurately direct the sound energy to produce optimum response from flaws. With different probe types and configurations, TRUSTIE can precisely measure depth and length of various flaws. It provides detailed flaw characterization to supplement eddy current results and can detect flaws that are below the ET detection threshold.

2.1 System Overview

Typical characteristics of the TRUSTIE system are:

- Inspection of tube with Inside Diameter (ID) from 0.31” to 0.54”
- Tube lengths up to 50’
- Normal beam and shear wave probes (frequencies ~15 MHz)

- U-bend inspections on 16” radius for 0.5” Outside Diameter (OD) tubes
- Typical probe rotation speeds of 600 rpm
- Automated data acquisition and remote analysis using Winspect software

2.2 Probe Technology

There are different types of TRUSTIE probes each designed to perform specific inspections. The Normal Beam (NB) and Shear Wave (SW) probes are configured to generate sound waves from the transducer to the tube surface at different incident angles. The straight leg and U-bend probes have different physical lengths. The U-bend probes are shorter to allow tight tube radiuses to be navigated. Figures 2, 3 and 4 illustrate different types of UT probe construction.

2.3 Inspection Capabilities

The TRUSTIE capability includes:

- Detection, sizing and characterizing of flaws (i.e OD pitting, micro-pits, corrosion, deformation, fretting, and circumferential/axial crack type flaws including ID Inter Granular Attack (IGA) and axial flaws)
- Profile characterization
- Inspection of U-bend regions
- Inspection of Preheaters
- Growth monitoring

The difference in tube sizes, SG configurations, and materials in CANDU SG tubes has led to development of a variety of UT inspections to accommodate the condition. Tube size and SG tube configurations limit the physical probe design. Tube mechanical properties have less influence on UT in comparison with eddy current testing. In response to the change in inspection needs and unique configuration requirements, various single element probes have been developed for various flaw characterizations to address tube degradation issues. UT scans provide detailed images of flaws and facilitates characterization of the degradation. Typical UT scan results are described in the Section 3 below to show the high resolution scanning capabilities of UT inspections for some specific applications.

TRUSTIE probes have evolved from the basic single element NB and SW probes to multi-element combination probe for improved inspection coverage, productivity and reliability [1]. For example, a combination probe shown in Figure 3 is designed with three UT elements which includes NB and two SW elements (axial and circumference orientation). The main function of the combination probe is to provide fast and reliable UT techniques to characterize various oriented flaws in a single pass inspection. The probe has been successfully prototyped and its performance under laboratory conditions is currently being evaluated.

A UT probe for assessing small radius U-bend configuration has also been designed and prototyped for inspecting low row U-bend using a miniaturized TRUSTIE U-bend probe concept (See Figure 4). This probe development program was funded by COG R&D programs.

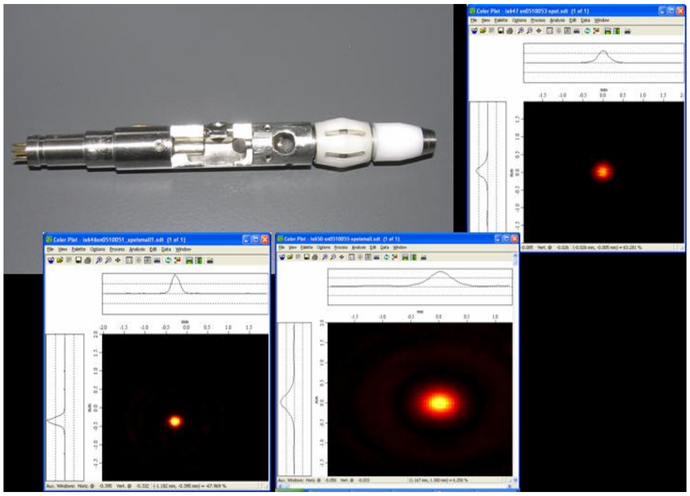

Figure 3. TRUSTIE Multi-element Probe

Figure 4. Tight Radius U-Bend NB Probe

3. History and Inspection Experience

The TRUSTIE technology was developed in 1993 to qualify the electrosleeve process and was field tested in SGs in late 1993 prior to the pilot inspection of insitu electrosleeves in 1994. TRUSTIE has since been used in many different CANDU SGs and is currently in use today. This section presents a historical perspective for ultrasonic inspection within OPG and highlights some of the results from the different SG tubes examined.

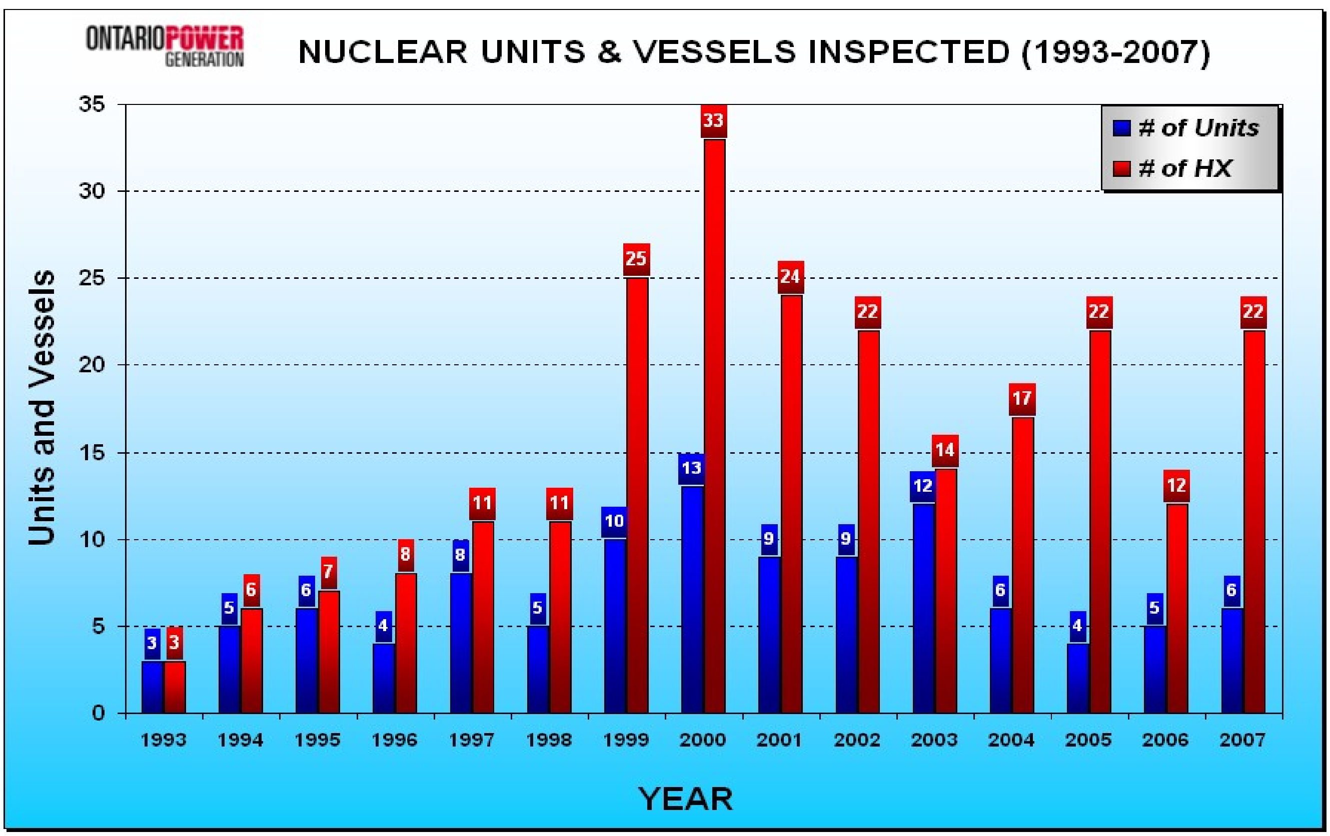

Figure 5. Number of nuclear units and vessels (SG3) inspected

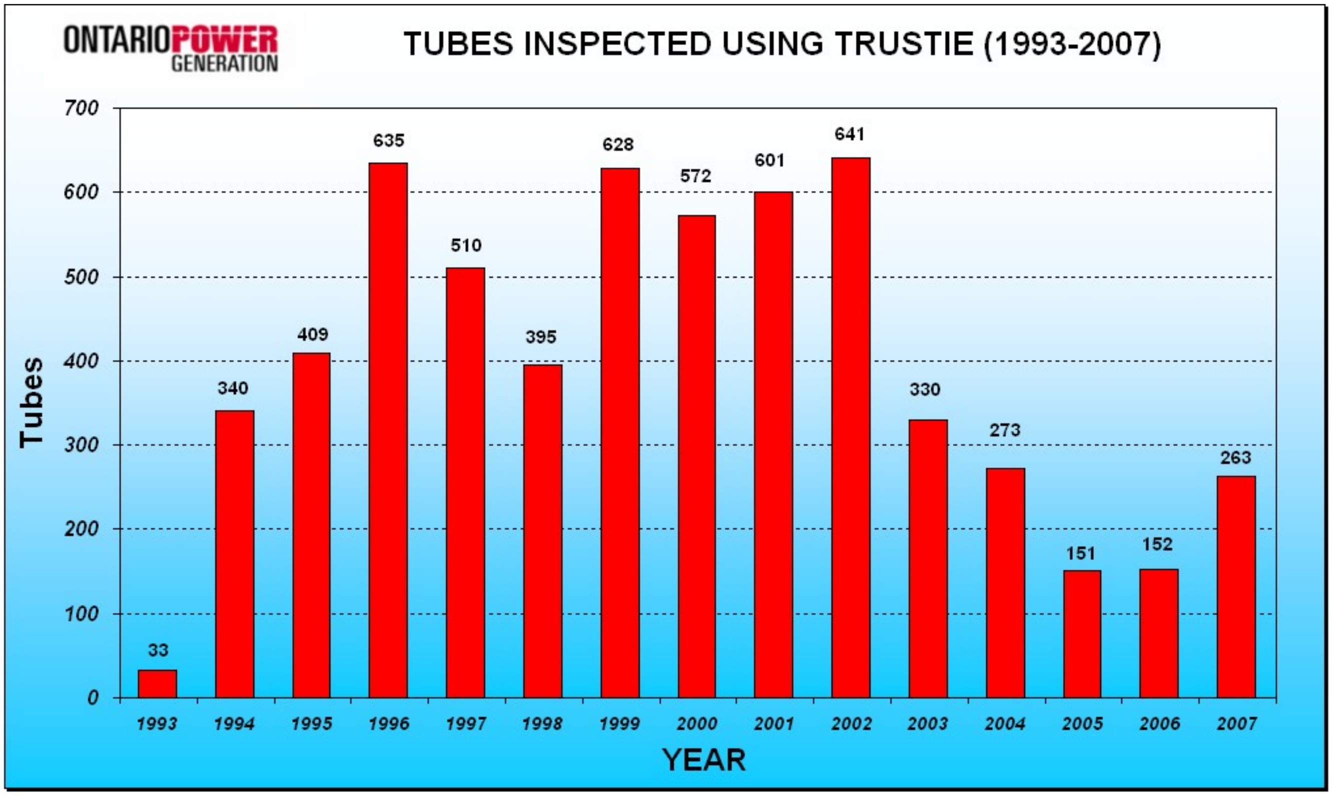

Figure 6. Number of SG tubes inspected

The charts in Figures 5 and 6 show the number of nuclear units, SGs and tubes inspected among OPG reactors over the period from 1993 to 2007. UT inspections are usually performed to verify ET results when detailed characterization is required to resolve unusual ET results. As a result, the UT inspection scope can vary depending on what ET discovers during the course of an inspection campaign. The high resolution capabilities of UT make it ideal for investigating SG tubes to detect early degradation, flaw morphology and for monitoring in-service growth of known flaws.

UT has proven to be a valuable diagnostic NDE tool to size and monitor growth of any flaws or indications found. Figure 7 & 8 shows detailed imaging and characterization of indications or flaws by UT scans, including tube deformation. Figure 9 & 10 shows the precise monitoring characteristics of UT for electro-sleeve and corrosion pits over years.

UT is also effective for inspecting and monitoring OD & ID surface flaws. Figure 11 & 12 shows UT scans of OD tube support frets and ID IGA. The UT imaging and characterization capability shown in the photos of the corrosion has been useful also in guiding metallurgical sectioning of specific flaws in removed tubes. See Figure 13.

An axial probe was specially designed and built to inspect ID axial flaws such as laps or cracks. ID flaws present a challenge for the NB probe to size because of their location and orientation. Therefore the UT technique requires both NB and SW probes to be utilized in the analysis of results in order to estimate the percent through wall size of the flaw. Figure 13 illustrates the UT measurements obtained on an ID lap from a removed tube in comparison with measurements from metallurgical examination. Often UT inspection plays an important role to assess the severity, monitor the growth of flaws in SG tubes, and provides critical information for fitness for service of SG tubing.

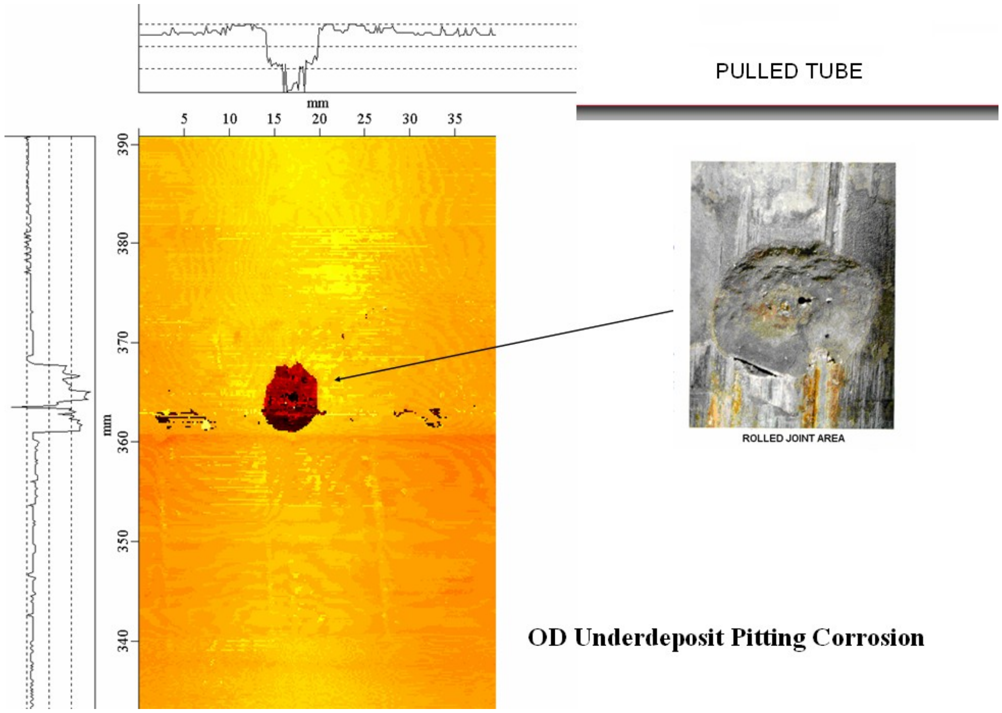

Figure 7. Ultrasonic image of severe tube OD pitting corrosion

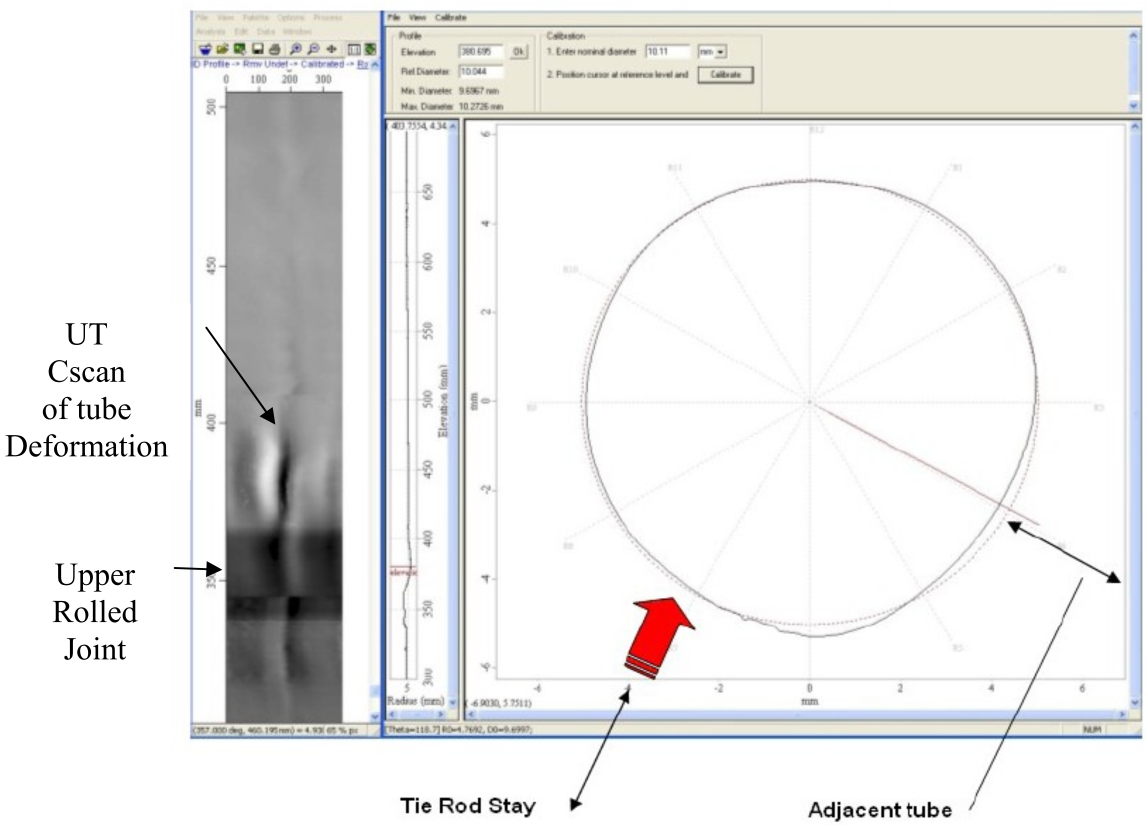

Figure 8. Tube deformation inspection using NB profiling

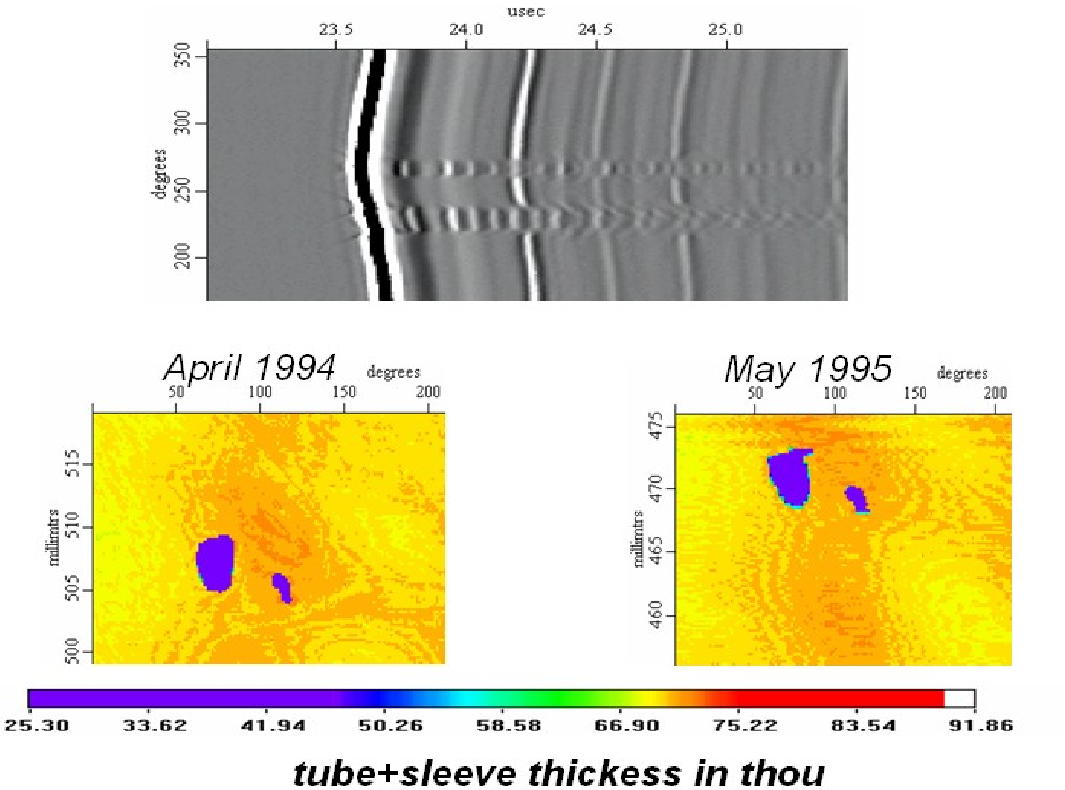

Figure 9. Electro-sleeve inspection in SG tube

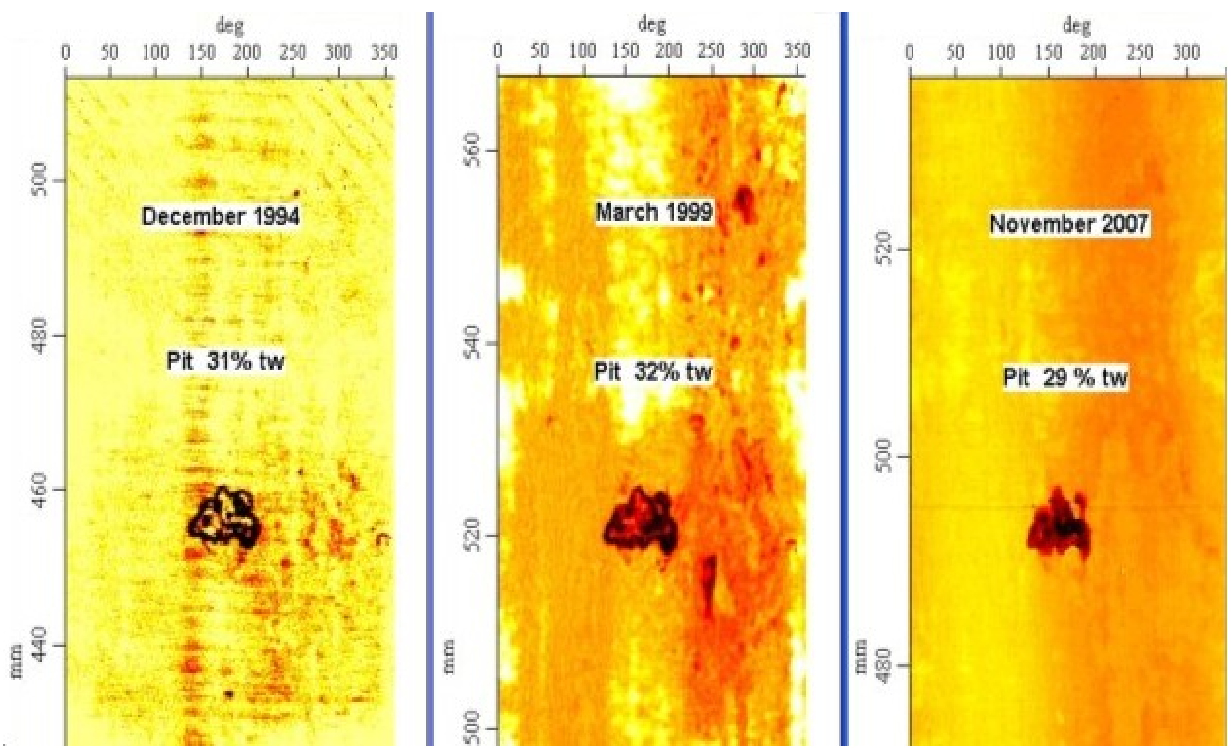

Figure 10. In-service monitoring of corrosion pitting (Sizing error tolerance is +/-5% tw)

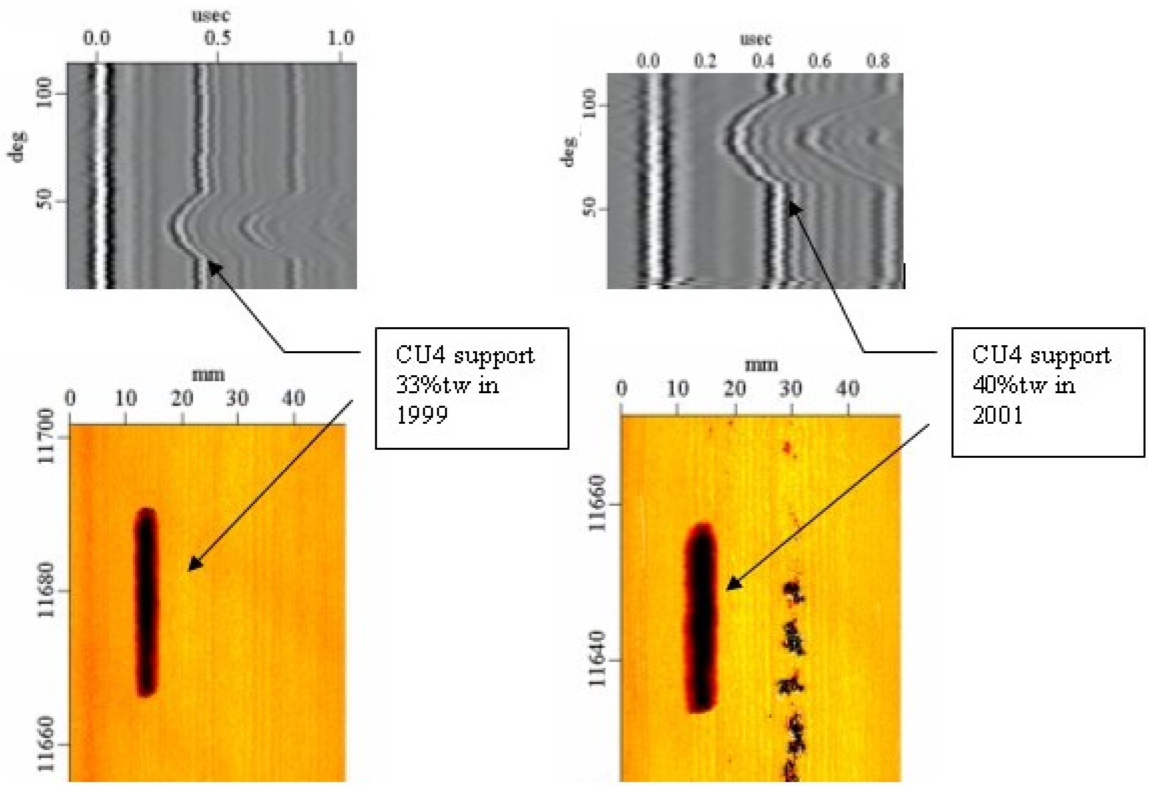

Figure 11. In-service monitoring of OD bar fretting

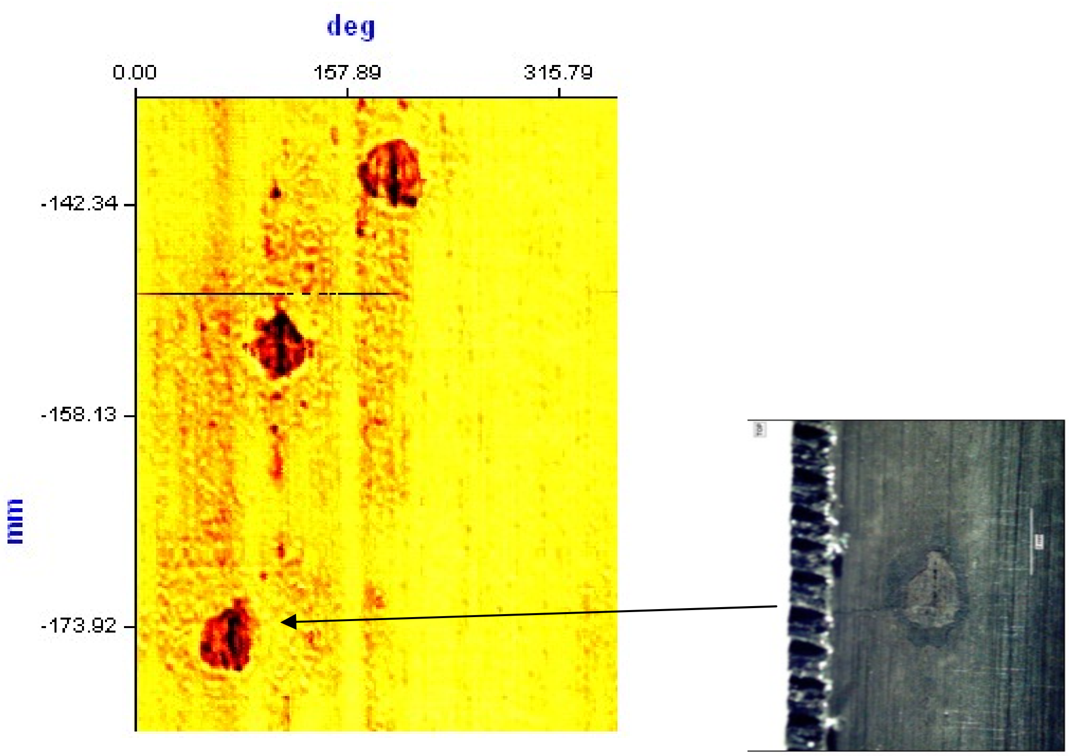

Figure 12. UT and optical image of IGA corrosion at tube ID surface

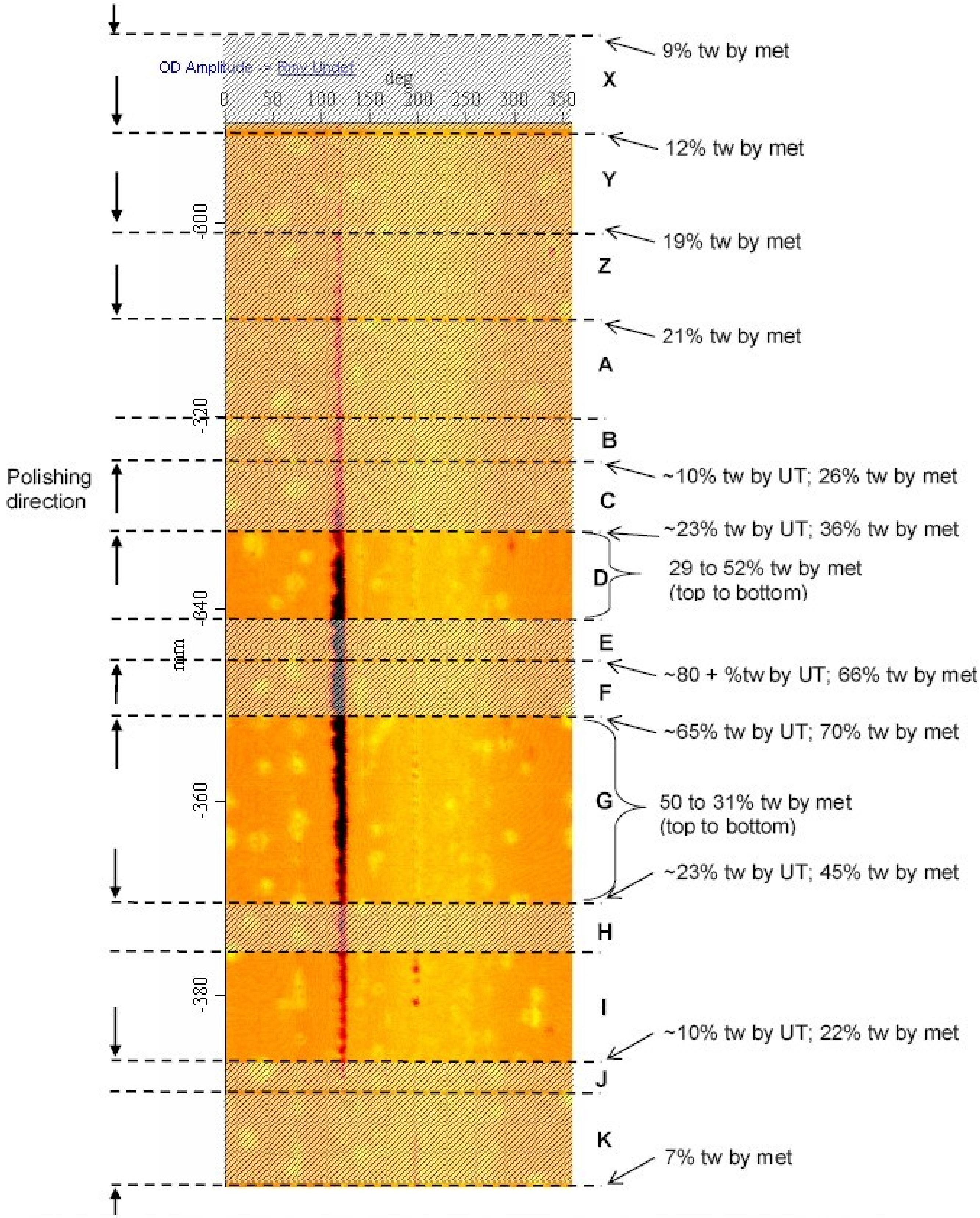

Figure 15. Estimated percent through wall by UT and metallography is indicated for an ID lap

4. Future Expectations

4.1 Equipment Enhancement

The major limitations of TRUSTIE inspections are the slower scanning speed and time consuming data analysis compared with eddy current inspections. The increasing demand of ultrasonic examination of SG tubes requires improved productivity and reliability. With the modern electronics and computer technology, the electro-mechanical drive system is currently being upgraded with high speed and high torque Servo motors for improved scanning performance. A fibre-optic cable network link is also being tested for remote data acquisition configuration. Some of this enhanced equipment is expected to be ready for field testing in 2008.

4.2 Future Probe Development

The normal beam probe has the longest history in TRUSTIE probe family. Its performance is satisfactory under most circumstances. However, different probe characteristics may be required for characterization of flaws such as IGA and magnetite deposits. Optimization may also be performed to further improve its sensitivity to detect and size flaws such as micro-pits.

Detection and characterisation of cracks can be a difficult task. This is partially due to the geometric limitation inside a steam generator tube and the curvature of a tube wall. The angled shear wave probes for crack detection and characterization can be optimised for ID and OD initiated cracks for improved performance. Computer modelling techniques can be applied to optimize probe parameters for different applications under different conditions.

Multi-element and phased array probes are very attractive due to its efficiency in inspection. It has been demonstrated that a probe with two ultrasonic transducers parallel connected to a single coaxial cable is feasible as long as the signals of interest are separated in time. The advantage of this approach is that it is fully compatible with the existing TRUSTIE system. A multi-element probe can also be operated with a multi-channel data acquisition system because the ultrasonic signal can be separate in time or space. A feasibility study of phased array application in steam generator inspection was conducted recently [2]. Phased array technology has the advantage of electronic beam steering; therefore, the mechanical rotation of the probe can be eliminated. The major challenge of applying a phased array probe arise from the small diameter of steam generator tubes and the current ability to manufacture a phased array probe that can perform adequately for the requirements of this application. With the development of piezo-composite material technologies, a 2D cylindrical matrix phased array with small elements may soon become feasible for use in small diameter tube inspection.

4.3 Advanced Data Processing

With the development of probe technology and increased capability in data acquisition and scanning, the amount of information that needs to be processed has increased significantly in the past few years. Development of new inspection techniques for existing and emerging types of flaws requires more sophisticated signal processing methods. This also requires an analyst to accurately and efficiently correlate more information than is traditionally required. Hence, an advanced data processing technique specialized in SG UT inspection needs to be developed accordingly. A methodology that provides advanced TRUSTIE data analysis and information management has been investigated recently [3]. It is intended to provide improvements in data processing efficiency, reliability and information management using computer software, database and communication techniques. It also provides an essential platform for the development of advanced signal processing algorithms for different types of flaws. The feasibility of an improved data processing methodology was investigated in 2007. The advanced data processing methodology focuses not only on the functions and tools to assist each individual analyst to perform data analysis efficiently but also on the speed of information flow and management in the light of the overall data processing process from raw data to a final inspection report.

The efficient performance of each individual analyst can be realized by high efficiency data visualization methods such as dynamically linked displays with tools to correlate between each data subset and by computer aided analysis tools for flaw detection, sizing and characterization. The high speed information flow can be realized by database and networking technologies. Measurement results and related information can be recorded electronically in a database and readily retrieved. An inspection report can be easily generated from the database. The database will also play an important role in historical inspection information management and in development of advanced analysis methods such as automated flaw detection and characterization using neural networks etc. Advanced data analysis tools utilizing these concepts as applied to UT data are currently being considered for future development.

5. Summary

TRUSTIE has produced unique quality in defect characterization over the years. It's sizing capability and precise imaging is most valuable and obvious. It provides a verification technique for eddy current tube inspection, giving more accurate depth sizing and flaw discrimination. It provides critical information to prevent unnecessary tube plugging and pulling. It also helps determine the fitness for service of steam generator tubing. UT is undoubtedly limited by its scanning speed, but its precise flaw sizing and characterization are often critical for a detailed SG tube examination. UT inspections associated with ET over the years contributes to a thorough and cost effective inspection for ensuring SG tube integrity.

As plant outages are scheduled for ever shorter windows for optimum economic use of CANDU power generation, the need to provide reliable and timely ultrasonic inspection results has become essential to avoid delays in the critical decision making process regarding tube plugging, inspection expansion due to discovery of new degradation mechanisms, and tube removal for metallurgical examinations. Advancements in computer technology and development in ultrasonic capability has made it feasible to significantly enhance both the hardware and software for the TRUSTIE system for future use. Research and development initiatives to improve ultrasonic technologies for SGs are currently being sponsored by COG programs. The field deployment, maintenance and enhancements to the existing working systems are an ongoing priority for OPG in order to meet the needs of the inspection programs for SGs in its operating plants at present and in the future.

6. Acknowledgements

The commitment and dedication of "Team TRUSTIE" members from Kinectrics, OPG and AECL has made it possible for the achievements described in this paper. The contribution of the many individuals to the accomplishments of the TRUSTIE equipment development and operations over the years is gratefully acknowledged. The ongoing support from COG (Ian Hey) and others is also appreciated.

7. References

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