INTEGRATED ULTRASONIC INSPECTION TECHNOLOGY TO MEET THE REQUIREMENTS OF CANDU STEAM GENERATORS

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Abstract

For over a decade, ultrasonic (UT) inspection techniques with TRUSTIE* have been providing inspection capability that can assess the severity of flaws in Steam Generator (SG) tubes, and accurately monitor their growth.

TRUSTIE, a high-resolution ultrasonic imaging system specialized for small diameter tube inspection, plays an important role in CANDU Steam Generator life cycle management. The increasing demand for production-oriented outage management strategies is focused on shortening outage windows. Advanced technologies in the areas of data analysis, multi-element probes, high torque servo systems, and integrated fibre-optic cable networks are being integrated into the existing TRUSTIE system to meet the new and challenging inspection requirements.

This paper presents an overview of the advanced technical developments and enhancements that are currently underway and being implemented for SG tube UT inspections in CANDU nuclear power plants.

* TRUSTIE™: Tiny Rotating UltraSonic Tube Inspection Equipment

1.0 Introduction

TRUSTIE is a high-resolution ultrasonic imaging system that provides the capability to accurately assess the severity of degradation, and monitor its growth in SG tubes. TRUSTIE technology provides detailed flaw characterization to supplement eddy current results and can detect flaws that are below the eddy current detection threshold.

Well established since 1994, TRUSTIE has been deployed for SG tube ultrasonic (UT) inspection in many CANDU steam generators [1] and has produced unique high quality results in defect characterization over the years. The TRUSTIE system sizing capability and precise imaging are 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 and also helps determine the fitness-for-service of steam generator tubing.

UT is limited by its scanning speed. It is generally not used for large volume tube examinations, but its accurate defect sizing and characterization capability are often critical for a thorough SG tube examination. Over the years, UT inspections associated in combination with eddy current testing (ET) have provided critical information in ensuring SG tube integrity.

Plant maintenance outages are scheduled for ever shorter windows to optimize economical use of CANDU power generation. As a result, the need to provide fast ultrasonic inspections has become essential, to avoid delays in critical decision-making processes related to tube plugging and inspection extensions due to the discovery of uncertain degradation mechanisms and tube removal for metallurgical examinations.

Ontario Power Generation (OPG) and Kinectrics Inc., with support from the CANDU Owner's Group (COG) have been working together for many years to advance UT inspection technologies, and to optimize inspections in order to meet or exceed the new and existing requirements. Advancements in electronics, computer technology, and ultrasonic technology have made it feasible to significantly enhance both hardware and software for the TRUSTIE system. As a result, new integrated UT inspection technologies are currently being developed and tested for field applications.

This paper provides an overview of the emerging integrated UT Inspection technologies for SG tubes in CANDU nuclear power plants.

2.0 Historical Design Overview

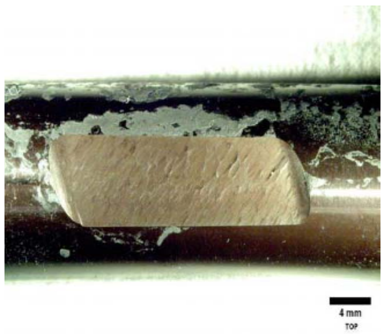
The first TRUSTIE system was built in 1994 and the overall construction of the current system is largely based on the original design. A standard TRUSTIE system consists of an electro-mechanical drive unit, a driveshaft and UT probe module, a motion control and data acquisition console, and a couplant supply subsystem.

TRUSTIE utilizes a manipulating arm such as Zetec SM-23 to position and deliver the probes. Figures 1 and 2 show a typical TRUSTIE system and a standard UT probe respectively. The axial and rotary drive unit located outside of a SG is remotely controlled to deliver the probe to perform scans. The driveshaft provides the mechanical and electrical connection between the probe and a drive system. Acquisition of the ultrasonic data is controlled remotely using commercial Winspect™ software (a Windows-based data acquisition and motion control software). Figure 3 shows an example that demonstrates its unique defect-imaging capability.

Electronic and computer technologies have advanced rapidly over the past decade. Some of the components used in the original TRUSTIE design are commercially obsolete. Consequently, maintenance and repairs have become difficult tasks and an upgrade using modern electronics and computer technologies is both desirable and necessary. The upgraded system will integrate the advanced technologies to enhance inspection capability and meet the increasing demand for higher productivity and cost-effective inspections.

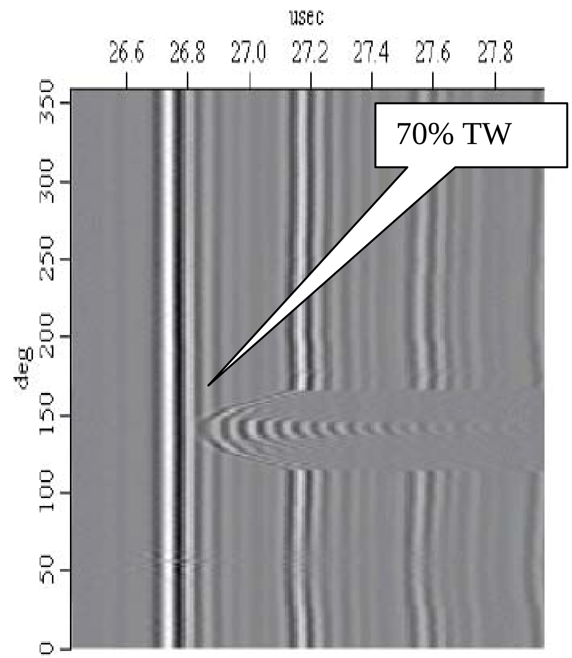
Figure 1: TRUSTIE Inspection System

Figure 2: A Standard UT Probe



(a) Optical Image

(b) C-scan Image



(c) B-scan Image

Figure 3: UT Images of an OD Fret and its Optical Image

3.0 Emerging Technology Integration

The productivity of UT inspection technology is generally limited to its scanning speed and data analysis is often a time-consuming and complicated process. The work tends to be hampered partly by the signal measurement process, and partly because of the complexity of signal interpretation. This presents a challenge for operator training and the use of complex probes.

Development of efficient data analysis methodology has become the prime priority of the integration effort. Developing multi-array UT probes for single-pass inspection associated with TRUSTIE has also been a high priority for some time—in parallel with advanced data processing—to improve productivity and reliability.

Work is currently underway to enhance TRUSTIE with up-to-date servo drive components to improve performance in scanning speed, driving torque and positioning accuracy. A fibre optic network-based TRUSTIE system is also being manufactured to meet new station requirements.

The envisioned integrated system, which consists of multi-element probe(s), advanced data analysis, up-to-date servo drive, and fibre optic network interface, is expected to improve TRUSTIE inspection capabilities, system reliability, mobility, and remote operation capabilities when the system is fully integrated. Figure 4 shows a simple flow model of the integrated approach.

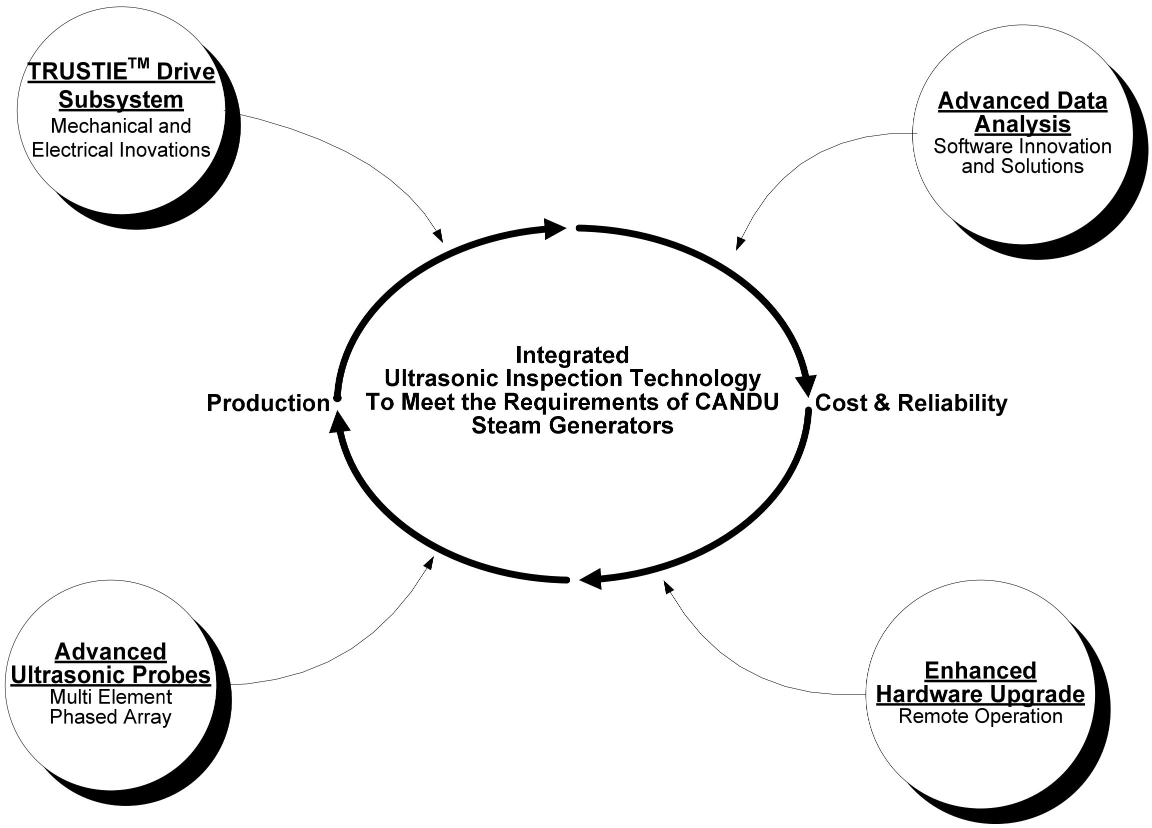


Figure 4: Integration Flow Model

4.0 Ultrasonic Probes

Different degradation mechanisms often require specific UT inspection probes for precise defect characterization [2]. Several standard TRUSTIE probes were manufactured for specific field inspections to address various defect sizing and characterization needs.

A traditional TRUSTIE probe utilizes a single element, focused ultrasonic transducer and special mirror / mirrors to direct the ultrasonic beam. Namely, the Normal Beam (NB) and Shear Wave (SW) probes are configured to generate sound waves with different incident angles at the tube surface.

The straight leg and U-bend probes have different physical lengths. The U-bend probes are shorter, to allow navigation of tight tube radiuses. The unique single element designs of the current TRUSTIE probes provide high accuracy in sizing and precise flaw characterization. Each probe design is tailored and optimized for a specific inspection requirement. It is time-consuming and inefficient to exchange probes during operation. Therefore, it is logical and cost-effective to apply a UT probe with multiple inspection modes—with the same capability as the existing single element probe for each inspection mode.

Development of probe technology for increased inspection coverage, reliability, and productivity, has evolved from the standard single-element NB and SW probes to multi-element combination probes [3] (as shown in Figure 5).

The main function of the combination probe is to provide fast, reliable UT techniques to characterize various types of flaws in a single pass inspection. Multi-element combination probes with different designs are currently being optimized, evaluated and qualified for field use. This work is sponsored by COG and OPG.

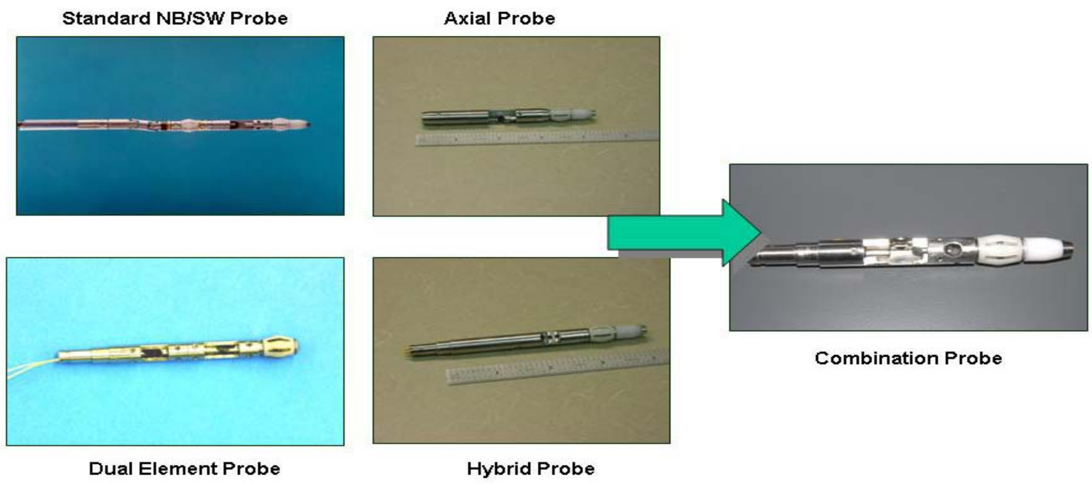


Figure 5: Evolution of Probe Development

Development of an array probe technology for high-speed single pass inspections is ongoing. A feasibility study for phased array applications in SG inspection was performed.

Phased array technology offers the advantage of electronic beam steering; therefore, the mechanical rotation of the probe can be eliminated. The major challenges for a phased array probe arise due to the small diameters of SG tubes in CANDU SG and, the current manufacturing limitations inherent in producing an array probe that can meet the unique ultrasonic requirements for sizing and characterization of SG flaws.

5.0 Advanced Data Analysis

The current UT data analysis is sometimes hampered, partially by its manual data processing and signal measurement processes, and partially by the limitations and subjectivity of interpretation—especially during a rush inspection campaign. With emerging probe technology and increased system capabilities in data acquisition and scanning, the amount of information that needs to be processed has increased significantly. An analyst will be required to accurately correlate more information than typically required by traditional training. This will most certainly require more efficient, sophisticated data processing tools, and methods, to assist analysts in meeting tight outage schedules.

Figure 6 illustrates the basic operations of a typical UT inspection campaign. Current data processing, as shown in Figure 6, relies heavily on manual input and information transfer for report execution, which is very time-consuming. It further poses reliability and efficiency issues, especially during parallel inspection campaigns and critical path activities. Electronic data processing and data management therefore become essential for efficient data integration and result coordination.

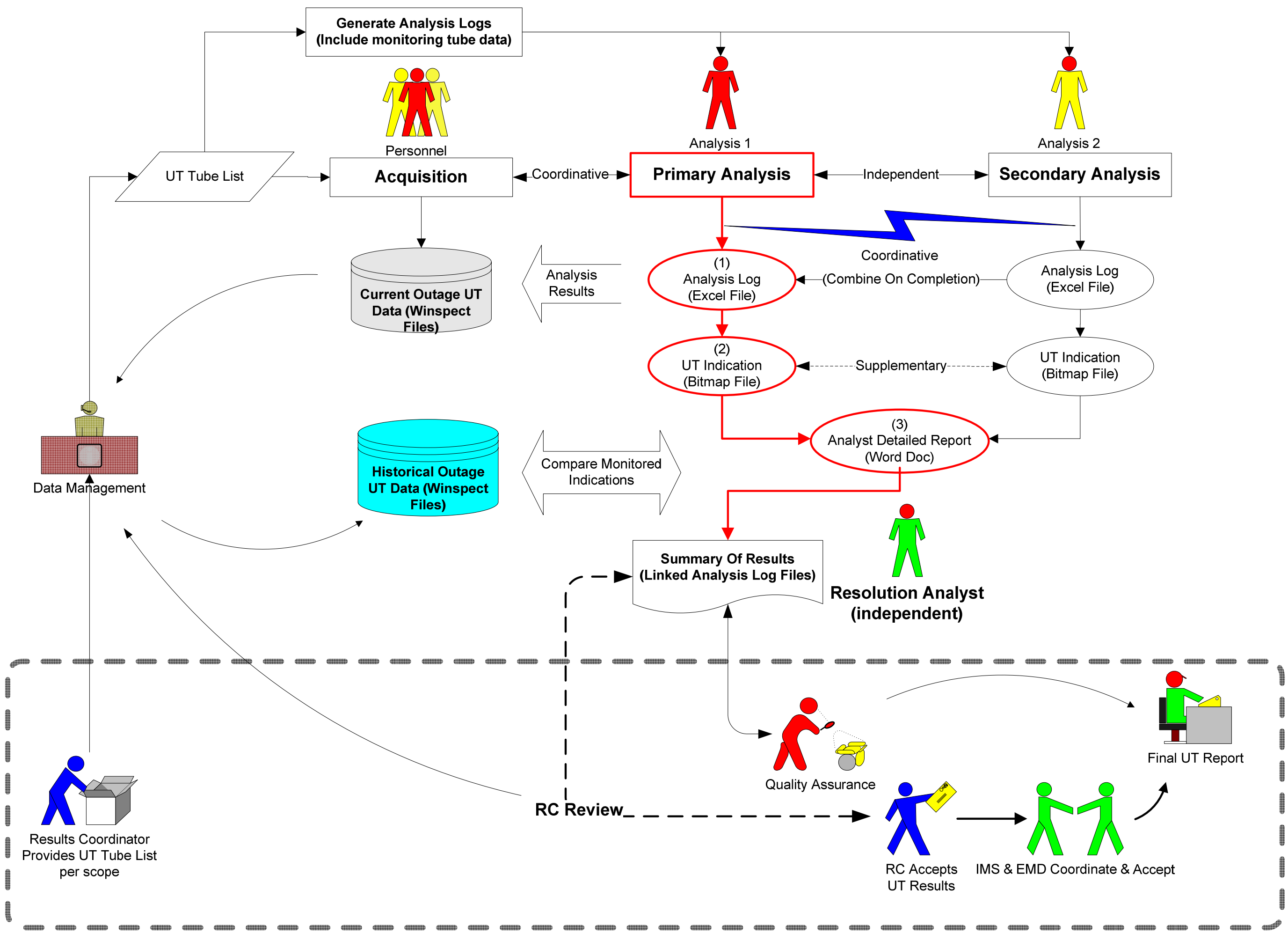


Figure 6: Generic Inspection Process Diagram

The envisioned integrated analysis and data management process [4] will provide a user-friendly interface, allowing a number and variety of technical personnel disciplines to gain access to its multiple functionalities.

The development process will take into consideration the transition from the existing UT acquisition and analysis software (Winspect™) to the next generation software. The primary objective of the new software is to minimize both manual data entry time and data entry errors, while maintaining high data integrity, as information is processed through the analytical process. It will integrate data retrieval, analysis and reporting procedures and include result-resolution procedures, UT result reporting and data export as shown in Figure 7.

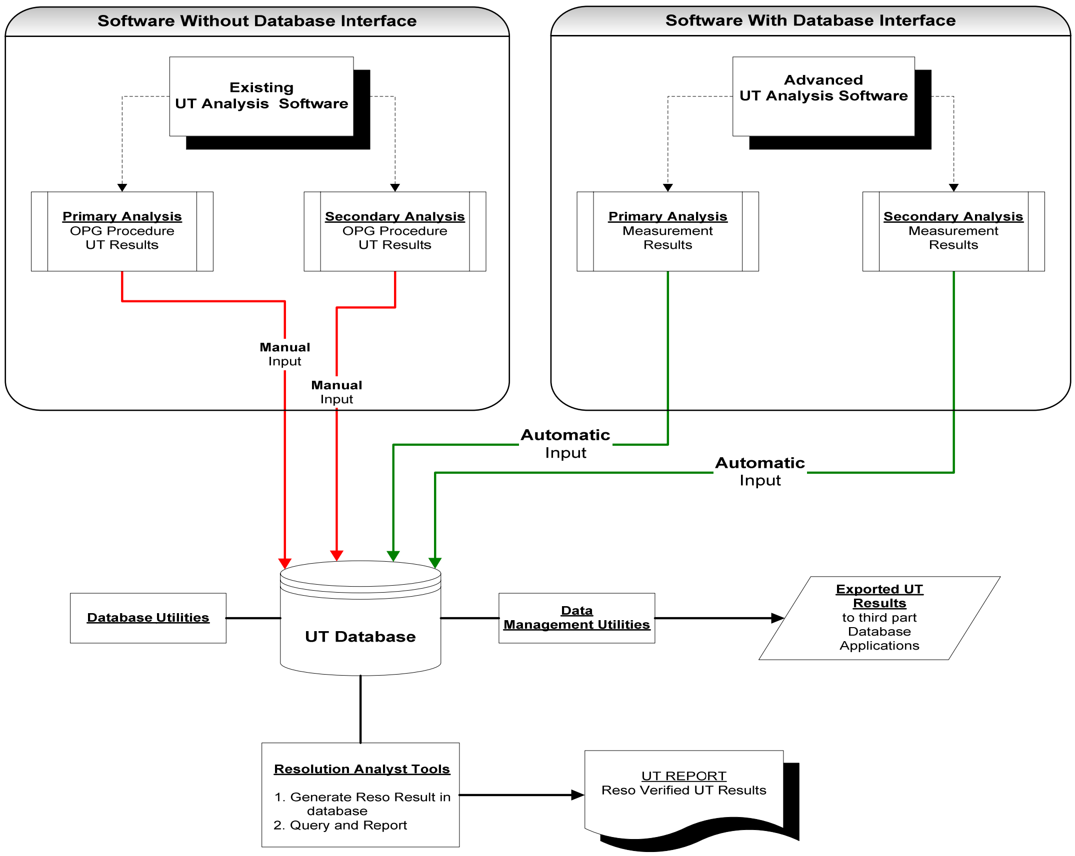


Figure 7: Planned Data Analysis Process

5.1 Advanced Data Analysis Platform

The current analysis techniques for UT data often require experienced, highly-trained analysts in order to achieve quality results. Analysts are required to examine large amounts of data for detailed flaw assessment in a short time frame. The use of computer software and database technologies is expected to greatly enhance the data analysis process. Data visualization techniques, computer-aided tools, electronic result tracking, database and advanced signal processing have been identified as the key areas for improvement.

The basic functionality often required by an analyst in the current UT practice are open files, such as display A-scan, B-scan and C-scan images, gating for waveform data, color palette manipulation, spectrum analysis, C-scan image rotation, and many measurement functions.

In addition to enhancements to basic functionality, the Advanced TRUSTIE Data Analysis software provides electronic tracking on all measurement and sizing operations, which facilitates verification and checking of results by a third party as required by quality assurance procedures.

Selected information will be stored in a database and the preliminary/secondary and resolution analysis process will be integrated as an on-line process. The inspection report can be generated with database and report utilities. A simplified structure of the advanced data analysis platform is shown in Figure 8.

The database is designed with consideration for future requirements, such as automated flaw characterization based on artificial intelligence and neural networks. The platform is an integrated data analysis environment.

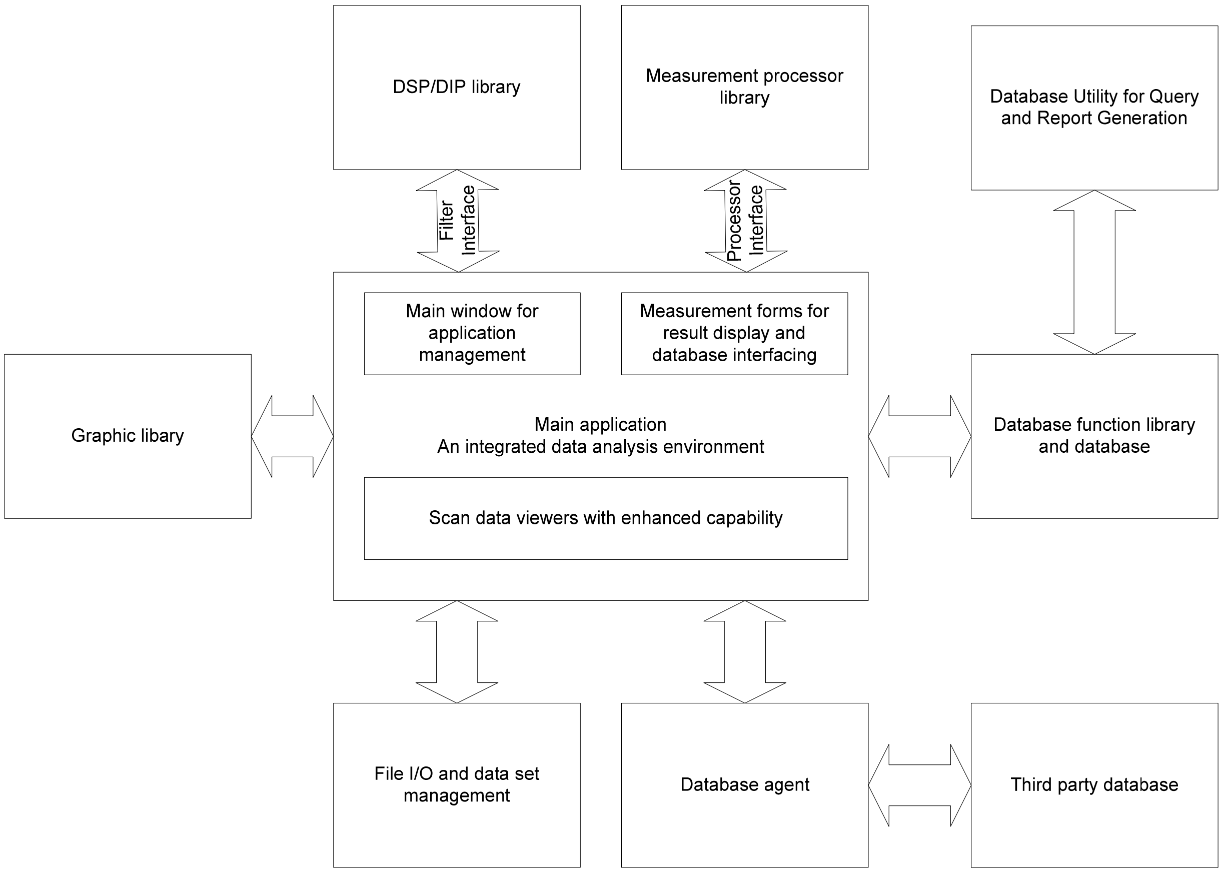


Figure 8: The Application Architecture

5.2 Enhanced Analysis Windows Examples

The advanced TRUSTIE software provides optimized functions to help analysts in signal visualization and decision-making. It will shorten turnaround time for the entire data analysis and reporting process. This section shows some examples of typical data presentation and analysis tools for measurement.

Figure 9 shows synchronized A, B and C-scan viewers, which are typically required for simultaneous viewing of data presented in multiple display modes. The advanced software is capable of reproducing multiple C-scan images from waveform data, and provides dynamically-linked displays. Figures 10 and 11 demonstrate the 3D visualization capability. Figure 10 shows a 3D presentation of the fret shown in Figure 9. The fret can be viewed from different angles. Figure 11 shows a C-scan image with its corresponding 3D presentation.

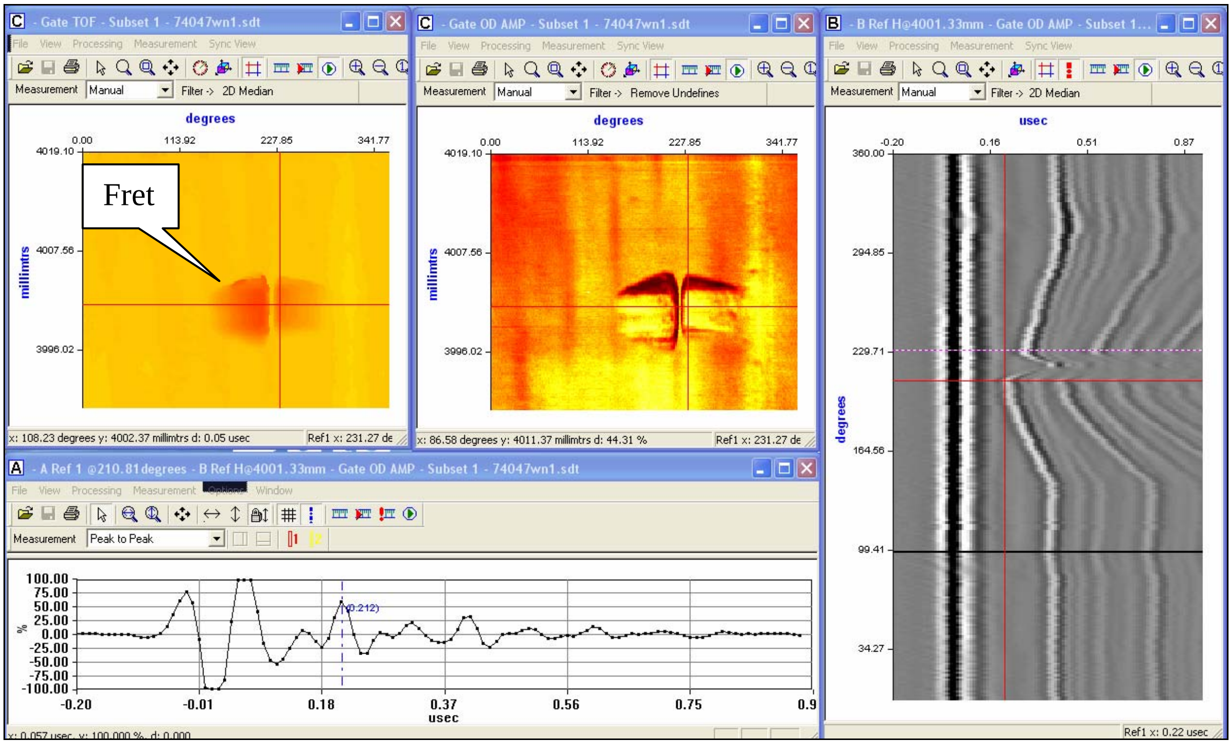


Figure 9: Synchronized A, B and C-scan Viewers

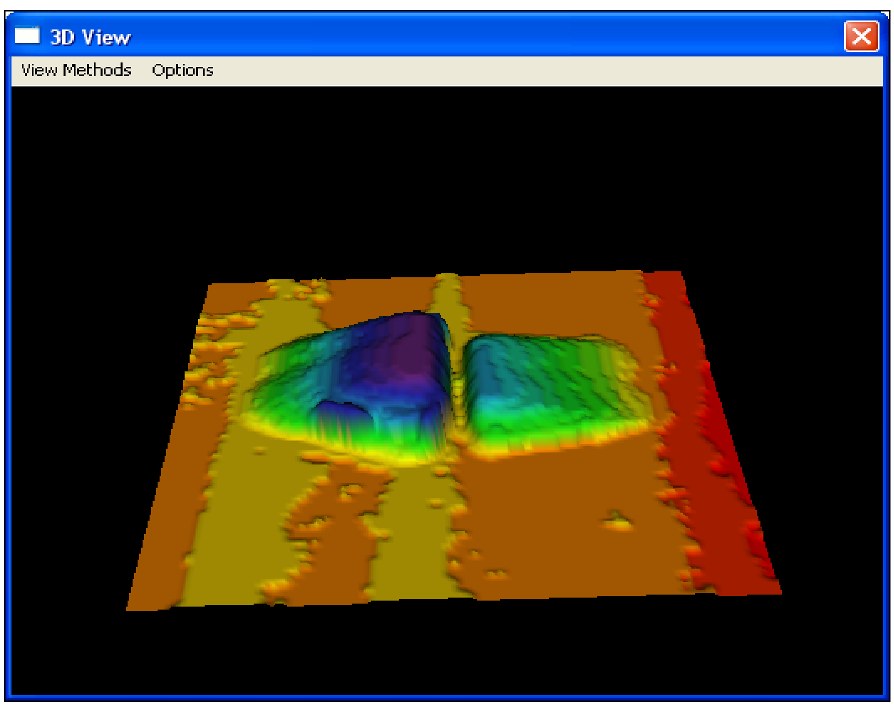


Figure 10: 3D Image of the Fret shown in Figure 9

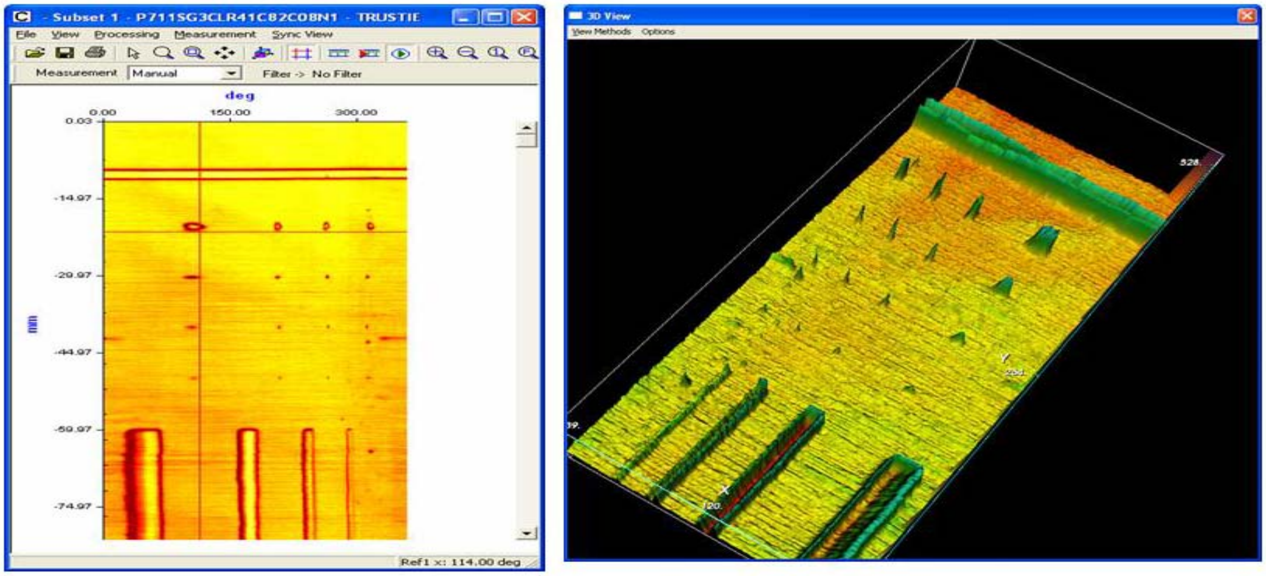


Figure 11: Typical 2D (left) and 3D (right) Visualization Displays

6.0 Enhanced Hardware Upgrade

In addition to development of the advanced data processing and single-pass probe system, fibre optic network connections and high torque servo systems are also critical to an integrated system meeting the future requirements for UT inspection. The TRUSTIE UT technology implementation plan aims to achieve both high productivity and cost reductions in the near future.

The current TRUSTIE data acquisition system is designed with a copper cable of length up to 600’ and the system must be operated via Reactor Building (RB) penetration in a location outside the RB. These conditions limit parallel inspection campaigns for multiple boiler units, and require frequent mobilization of the trailers that house the control equipment.

Fibre optic-based penetrations in reactor vaults have recently become standard for remote operation inspection equipment. A fibre optic connection with specific interface components for the UT system is being designed and constructed to conform to the emerging standard fibre based penetration. A new package of interconnection components is being specially-designed and built to link fibre optic modules to a remote UT acquisition control system located inside a trailer.

A standard TRUSTIE inspection system is currently equipped with stepper motors for axial and rotary drives. The stepper motor drive subsystem was developed in 1993. Some of the stepping motor components are obsolete and no longer commercially-available for replacement and maintenance.

A servo motor drive system has recently been designed and integrated into the TRUSTIE system. This drive system can potentially provide less noise interference to ultrasonic signals and higher torque delivery for scanning motions, especially for tube conditions with thicker magnetite layers.

Both the fibre network linked TRUSTIE system and the servo drive are currently undergoing a series of functional tests to assure functionality and compatibility with existing TRUSTIE operation procedures. The fibre-optic network based TRUSTIE system will be able to perform remote inspection operations with a fibre link from a distance up to 1 km. The standard UT A-scans, C-scans and waveform files will be generated, stored, and transferred through the fibre link. Remote control of the couplant supply sub-system, impedance match unit (if required), and drain solenoid will be tested over the fibre link for their functionality.

7.0 Summary

Over the years UT inspections used in combination with ET have contributed to thorough SG tube examinations, and provided critical information for SG life cycle management for many CANDU reactors. TRUSTIE helps determine the fitness-for-service of SG tubing. Generally, UT is limited by its scanning speed, but its accurate flaw sizing and characterization often outweigh this disadvantage.

For decades, TRUSTIE technology has been recognized for its vivid imaging capability and accurate defect characterization. With emerging multi-element probe technology and improved system capabilities in data acquisition and scanning, the amount of information that needs to be processed is expected to increase significantly. This will most certainly require more efficient and sophisticated data processing methods and techniques. The advanced data analysis platform, as described herein, will be integrated to assist operators in efficient signal analysis and reporting. The processing and analysis technique developed will form the basis for future development of automated data analysis techniques. The platform provides an environment to implement new algorithms for processing different types of flaws and new degradations.

As plant outages are scheduled for ever shorter windows to optimize CANDU power production, the need to provide timely and cost-effective ultrasonic inspection has become essential to avoid delays in the critical decision-making process. OPG and Kinectrics have collaborated to develop and integrate new UT techniques, automated data analysis and high-speed systems to meet the present and future challenges of nuclear industry SG inspection requirements. Research and development initiatives to advance data analysis software and probe technologies—currently sponsored by COG programs—have established a foundation to achieving the ultimate goal of integrated UT Technology.

8.0 Acknowledgements

The commitment and dedication of “Team TRUSTIE”, with members from Kinectrics, Ontario Power Generation and Atomic Energy of Canada Limited has made possible the achievements described in this paper. The contribution of the many individuals in the accomplishment of TRUSTIE equipment development and operations is gratefully acknowledged. The ongoing support from CANDU Owners Group and others is also greatly appreciated.

9.0 References

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