FRET REPLICA INSPECTION LASER SCANNER (FRILS)

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ABSTRACT

In the stress analysis of flaws and artifacts found in pressure tubes, it is crucial to have detailed knowledge of the flaw geometry. Fuel channel inspections by ultrasonic or eddy current inspection methods alone cannot provide the complete required geometry information. Replicas, which are a negative impression of surface pressure tube indications, are scanned with a laser system which will provide the additional detail required.

FRILS was initially developed in 1993 to establish in-house capability of profiling indications on the inside diameter surface of pressure tubes. The need of this profiling was initially a response to the discovery of fuel bundle bearing pad fretting (FBBPF) caused by flow induced fuel bundle vibration. The benefits of the system were soon realized as a tool for profiling debris type indications. Although the primary use of FRILS is to profile FBBBF and Debris Fretting, since its inception the FRILS inspection system has become an instrumental tool in flaw assessment for:

- Fuel Bundle Bearing Pad Frets (FBBPF)
- Debris Frets
- Scratches
- Crevice Corrosion
- Oxide Jacking
- Areas of surface roughness
- Weld Profiling

Replicas are collected via acquisition from tooling on both the Channel and Gauging Apparatus for Reactors (CIGAR) and the Advanced Non-Destructive Examination (ANDE) systems.

The ANDE system is a high speed data acquisition system which includes both an ultrasonic inspection tool and a replication tool. Although both of these tools were designed to be delivered with the UDM, the platform for these tools was built with flexibility allowing for adoption to other delivery systems. These tools were based on the experience of the CIGAR inspection system. The CIGAR system has also undergone many system upgrades resulting in reduced inspection times.

The FRILS system – Fret Replication Inspection Laser Scanner system was developed and has been upgraded to meet the demands of the improved inspection and replication systems. FRILS provides the knowledge of the flaw geometry that could ease restrictions placed on the unit based on the cycle limitations due to the flaw assessment.

Once the replica is produced it is inspected utilizing the Fret Replication Inspection Laser Scanner System (FRILS). The results obtained from the FRILS scans are utilized in the flaw assessment. These scans provide information on the flaw geometry – length, width, depth, and root radius of the flaw. In basic terms, root radius is a measure of how sharp the edges are in the defect. The resultant data is utilized in the stress analysis calculation that ultimately determines how many shutdown cycles that the reactor can have before that flaw must be re-inspected.

The FRILS System utilizes light profilometry. A narrow light stripe is projected onto the replica surface, a camera with zoom optics is positioned at a calculated angle to the surface and this image is then projected onto a calibrated monitor. An image processor extracts and digitizes the surface profile. FRILS custom designed software is used in the collection and analysis of this data.

This paper will present details of the FRILS system capabilities, the evolution to the second generation FRILS system and field execution of the FRILS Inspections at Ontario Power Generation reactors.

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1.0 Introduction

In the late 1980s the fuel channel inspections became enhanced with the introduction of the volumetric ultrasonic CIGAR system. The addition of the B-Scan to the CIGAR system which is used determine flaw depth, became an important tool for the fuel channel fracture analysis. It became apparent that a tool was needed to determine flaw geometry and root radius.

Replication tools were developed to take an impression of ID flaws in the early 1990s and in parallel the FRILS system was developed to obtain information from the replicas, non-destructively. FRILS was designed to supply detailed qualitative information of the flaw geometry to aid in the stress analysis of flaws found in pressure tubes. More specifically the resultant data from the FRILS scans supply a method of measuring root radius, length, width, depth measurements, and angular orientation.

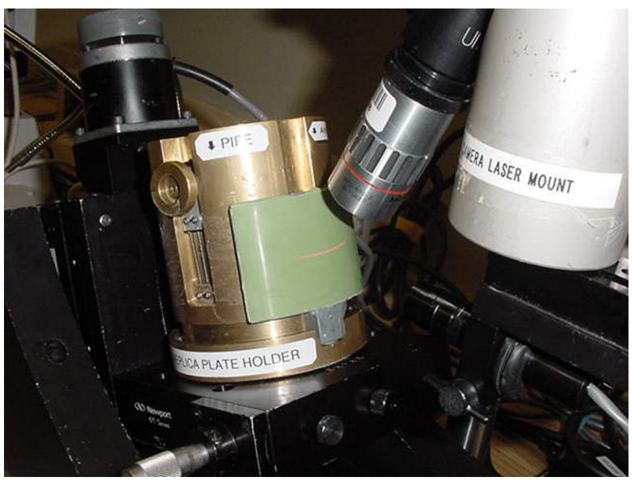

Figure 1 Laser Stripe on Replica

The FRILS system completed its field trials in 1993 and has been involved in numerous campaigns supporting Ontario Power Generation, Bruce Power and Hydro Quebec. There are now two FRILS systems in the field. FRILS inspection has developed beyond fuel channel inspection, to include replicas coming from feeders, instrumentation tubing, tube sheet replicas and fracture study replicas.

The FRILS system has evolved into a system that utilizes optical imaging for a replica quality indicator as well as a tool that will support or supplement dimensional and root radius information of indications replicated.

The entire FRILS system is comprised of the FRILS Scanning Rig, the Optical Microscope and the Stereo Electron Microscope; this paper will detail the FRILS Scanning Rig and the Optical Microscope.

2.0 System Description – Overview

The FRILS system is a portable system that can be deployed rapidly, set up within 24 hours at site locations.

The FRILS system can be used to assess the replica plate positioning in relation to the flaw to optimize compound flow in the flaw cavity, this information proves useful in the event of further replication of the flaw. In addition the replica quality can be determined. Replica quality is a critical item to ensure quality results are been given.

FRILS uses a narrow stripe from a laser projected onto the fret replica. A CMOS digital camera with zoom optics is positioned at a known angle to the surface of the replica and takes a digital image of the scan line. An image process extracts and digitizes the surface profile. FRILS analysis software is used to present the data and provide the analytical capability. The computer system interfaces with the operator, CMOS camera and motor controllers.

The acquisition process is available in the on screen procedure starting with the calibrations and providing instruction through the various scans as required.

The FRILS system is calibrated prior to each campaign and verified prior to and after each replica plate scanned. The calibration check involves assigning scale factors based on the known dimensions of the calibrated standard test specimen.

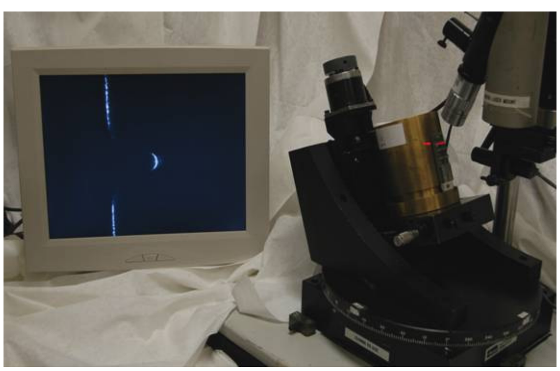

Figure 3 FRILS Scanning RIG

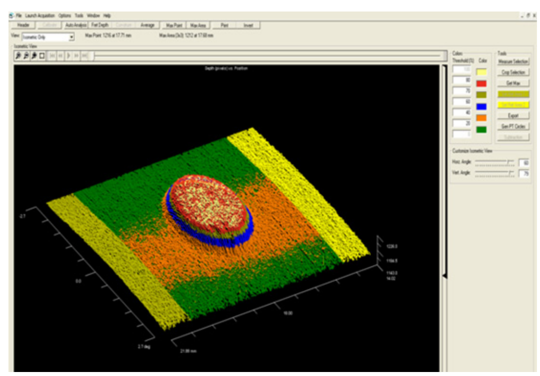

Figure 2 FRILS Isometric View

3.0 Evolution to the Second Generation FRILS System

After successful service of over 15 years, certain components of the FRILS System had become obsolete; upgrading these components necessitated the upgrade of the FRILS computer and software. In addition to the obsolescence issue was the increased demand for detailed information on the flaw geometry and the replica quality.

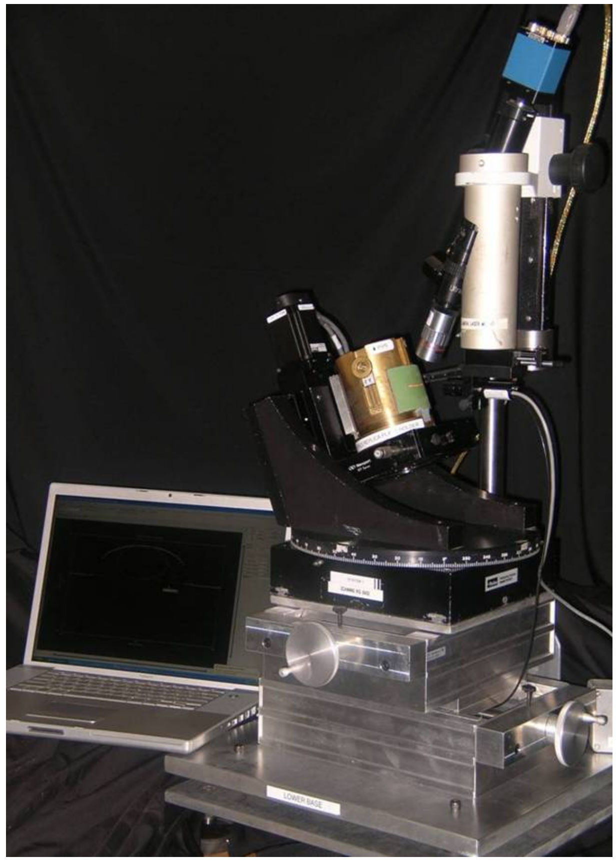

Figure 4 FRILS Scanning Rig

The FRILS upgrade of hardware and software was completed in a two phase approach. The first phase was to upgrade the FRILS Acquisition Systems obsolete hardware components, including the frame grabber card, CCD camera and stepper motors. Hardware replacements are commercially available components that allow for further upgrades.

Included in phase one are the updates to the FRILS Acquisition Software. This update allows for the FRILS Acquisition Software to run on current versions of Windows Operating Systems (2000/XP). The upgraded software provides for an improved GUI, which offers greater flexibility for detailed scan parameters and camera image adjustments. The software program is designed to easily support new hardware in the event of future upgrades. In addition to the elimination of the frame grabber card the CCD camera was replaced with a CMOS camera, capable of higher resolution images.

Figure 5 – Laser Line Generator

Phase 2 covered enhancing the analysis software by taking advantage of the new video resolution which is possible based on the CMOS cameras and the replacement of the video card. Phase 2 also saw the introduction of a new Laser Line Generator which provides a 25% tighter laser stripe. The analysis software upgrade includes; tools for both automatic and manual analysis, a modular design to support new analysis algorithms, automatic report generation, automatic calibration and verification of the calibration values.

4.0 System Capabilities

These upgrades have provided a FRILS system which is capable of scanning with a narrow 20 micrometer laser stripe. The CMOS camera provides a field of view covering up to a 12 mm width and a 60 mm in length per scan pass.

The FRILS system has a depth resolution to better than 5 micrometers.. The root radius measurement can be measured for a radius greater then 40 micrometers. Length and width accuracies are better than or equal to 0.5milimeters.

Although the FRILS system was designed and is used primarily for pressure tube replicas, the system has demonstrated it's adaptability to provide data for replicas from other system area including: weld profiling for feeder welds, calandria tube bore sheet replicas, fracture analysis and instrumentation tubing.

The resultant data from a FRILS scan is used to provide flaw geometry, including root radius information. Auto analysis reports fret depth, width and length. Manual analysis is utilized to verify these values.

The FRILS system is a stand alone system requiring only 120v power and LAN access. The utilization of a Controlled At The Source Area (CATS) not only expedites the scanning process, but also adheres to the radiological waste reduction programs.

5.0 Scanning Rig

The components of the FRILS scanning rig are:

- the anti-vibration base
- linear and rotary stages
- scanning rig base
- motor controllers
- camera / laser mount assembly
- laser assembly

The scanning rig is mounted upon the anti-vibration base. This anti-vibration base is equipped to provide fine control for X and Y positioning. X and Y positioning of the scanning rig base is essential for optical centering, which is critical for the correct triangulation of the replica position in relation to the camera and laser.

The linear stage and rotary stage are maneuvered via stepper motors. These stepper motors are controlled through Ethernet ports on the FRILS computer.

The CMOS camera is mounted on the camera/laser mount assembly. This camera is capable of 29 fps at 1280 x 1024 resolution. The elimination of the frame grabber card was a result of the CMOS camera communicating directly with the host computer through a fire wire interface. There is also a zoom lens which is limited to high and low magnification settings. The zoom lens contains the camera focus bezel.

The laser stripe generator is mounted on the laser focus stage. The laser intensity controller modulates the power to the laser which allows for changes in the intensity of the laser. Changing the laser intensity is required depending on the surface texture of the replica compound, and the zoom factor used.

6.0 Microscope Imaging

All replicas are first viewed using a stereomicroscope. This examination allows for optical assessment of the condition of the replica and to characterize the flaw.

The microscope optical system is a parallel-optics zoom system with a total magnification of 3.75x-540x depending on the eyepiece and objective used, a zoom range of 0.75x-11.25x and a zoom ratio of 15:1.

Figure 6 Microscope

The microscope is equipped with a motorized stage allowing for remote X and Y axis movements, a Z motor which provides remote Z axis movements, along with a fiber optic ring light and fiber optic goose neck lights.

A 5 mega pixel camera is mounted on the microscope to capture digital images, extended depth of focus (EDF) images, 3D images, and stitched images. The camera is controlled via a separate controller, and a computer.

The camera, stage and Z motor are remotely operated via software installed on a laptop computer. This remote operation is critical in limiting the spread of contamination, and in dose reduction to the operators. The software allows for, manual length and area measurements, large imaging stitching, EDF, which creates an all-in-focus image from a series of Z-axis images, stereovision images & 3D surface images to achieve virtual 3D and image capture.

The optical assessment of the flaw is first performed under low magnification to verify the flaw characterization and to compare with the C-Scan printout. The replica is assessed to determine if the replica is torn or incomplete. On subsequent replicas different axial and rotary positions are often used to improve the quality of images. Utilizing a range of magnifications often assists in discerning these features; if there is evidence that the replica may not be complete further examination may be performed utilizing the Stereo Electron Microscope.

The images produced by the microscope are often used in reports and assist the flaw analyst with a complete picture for assessment purposes. If desired the microscopic images can be viewed by offsite personnel via live streaming.

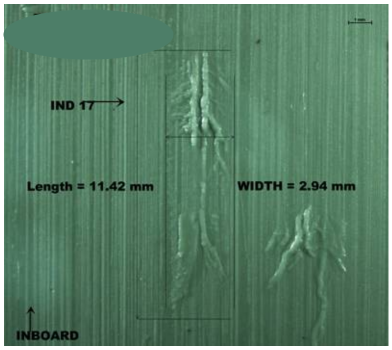

Figure 7 Low Zoom Optical Image

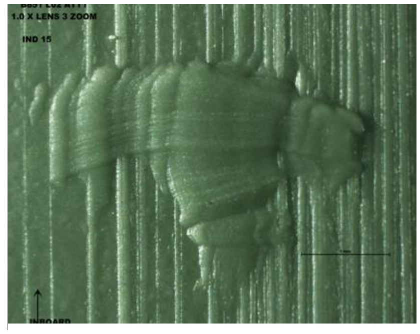

Figure 8 High Zoom Optical Image

7.0 Replica tools and Compound

Tooling for replication varies from the automated machine delivered single plate CIGAR replica tool to the ANDE double plate replication tool to the to the manual triple plate calandria tube replication tool, and the other manual methods used to replicate instrumentation tubing and feeder welds. The FRILS plate holder can be adapted to meet the various sizes of plates, utilized for these methods.

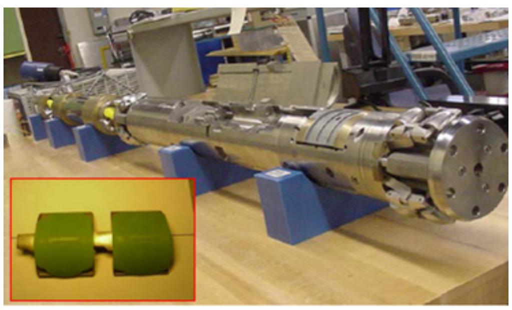

Figure 9 ANDE Replication Tool

Figure 10 CIGAR Replication Tool

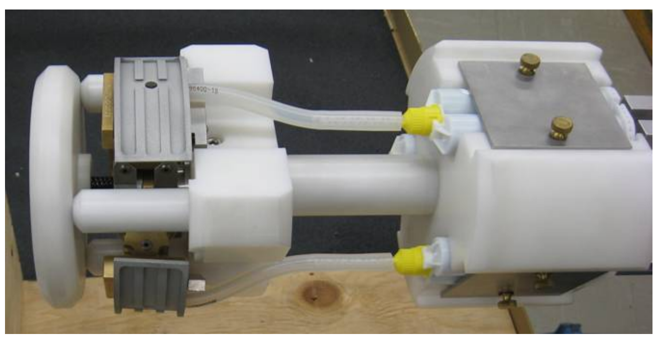

Figure 11 Calandria Tube Bore Sheet Replication Tool

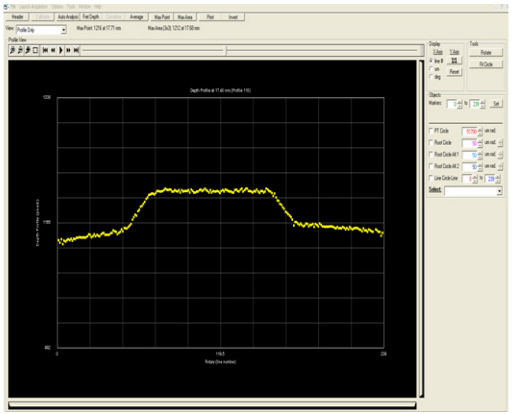

Figure 13 FRILS Profile View

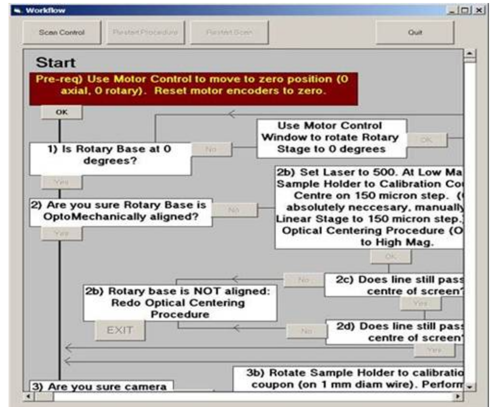

Figure 14 FRILS on Screen Procedure

The analysis software is designed with tools for both automatic and manual analysis to obtain depth, length, width and radius measurements. The analysis software also provides automatic report generation; this report tracks all of the depth and root radius measurements made by the user during analysis. This software also performs automatic verification of calibration values. The program is modular to support new analysis algorithms without changing the acquisition components.

9.0 Site Experience – OPEX

The upgraded FRILS system was first used in the spring of 2007 on 7 replicated indications. Each indication was processed through the entire FRILS system within 8 hours. Since this campaign, FRILS has been used at site seven more fuel channel inspection campaigns. As with any new system, as the crews have more hands-on experience they are able to become more efficient on the equipment and the sequence of operation. Continuing training, procedural upgrades and streamlining has brought the average flaw processing time down to 6 hours. Time savings to critical path are also realized with the portable SEM which is available at site, reducing the need for rush radioactive shipments for SEM examination at off site locations.

The second generation FRILS system has successfully been used on 8 campaigns and has provided geometry information on:

- Fuel Bundle Bearing Pad Frets (FBBPF)
- Debris Frets
- Scratches
- Crevice Corrosion
- Areas of surface roughness
- Weld Profiling
- Scrape Cutting Tool profiling

10.0 Conclusion

The demand for the FRILS system has grown substantially with inspections providing much greater number of replicas than originally projected in 1993.

The FRILS system has seen many years of service, there have been significant changes to the footprint of the system. These changes have produced considerable critical path savings. The improvements in the quality of images and the quality of scans have proven to be an invaluable tool for flaw assessment. This is not only a result of the quality of the images but the ability to provide zoomed stitched images and EDF images which provide zoomed areas completely in focus.

The FRILS system offers a facility for fast and reliable quantitative evaluation of replicas, a key feature of this system is the capability for root radius measurements.

The rapid response of FRILS has proven to be an effective tool at saving critical path time; the on site data collection provides the flaw assessor with resultant data, optical images and if required SEM images within hours of receiving the replica. This data enables the flaw assessor to make quick decisions which directly impacts critical path time.

The updates to the FRILS system are quickly proving themselves as the quality of the data and images have improved to a point where the replica evaluators can typically make a determination on the replica in hours hrs compared to the 2-3 days it took prior to the upgrades.

11.0 Acknowledgements

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Glossary

ANDE: Advanced Non Destructive Examination
CATS: Contain At The Source, a contamination control process
CCD: Charge-Coupled Device
CMOS: Complementary Metal Oxide Semiconductor
C-SCAN: a two dimensional presentation of ultrasonic data
EDF: Extended Depth of Focus
FPS: Frames Per Second
FRILS: Fret Replica Inspection Laser Scanner
FBBPF: Fuel Bundle Bearing Pad Fret
GUI: Graphical User Interface
ID: Inside Diameter
IM&CS: Inspection Maintenance and Commercial Services
OPEX: Operating Experiences
SEM: Scanning Electron Microscope
UDM: Universal Delivery Machine
UT: Ultrasonic Inspection
3D: Three Dimensional