

## **Pressure tube flaws and artifacts observed in CANDU fuel channels; detection, sizing and characterization issues**

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### **Abstract**

Ontario Power Generation; Inspection & Maintenance Services Division (IMS) has been operating a variety of inspection systems to perform volumetric and surface nondestructive examinations of the CANDU reactor pressure tubes. Experience acquired over more than 20 years allows for relatively reliable detection, sizing and characterization of various flaws and artifacts present in pressure tubes. The inspections have been performed in various reactor configurations, currently in operation in various countries, including multi and single unit stations, AECL and Ontario Hydro designs. There are several ways to categorize pressure tube flaws. The categorization can be based on source of flaw (manufacturing, installation or in-service), flaw location (ID, OD or material) and flaw severity. The proper characterization of detected flaws is extremely important for the engineering assessment as some categories of flaws may be assessed as blunt whereas others must be assessed as sharp. This has a serious impact on reactor's operating restrictions.

This paper will discuss examples from each category including detection, sizing and characterization issues specific to each group of flaws. Thanks to the large number of tubes inspected over the years, OPG-IMS has collected an extensive "library" of information with respect to the pressure tube flaws. Many of the flaws have been also replicated providing additional information which complements or validates NDE data. Non destructive methods currently employed for pressure tube inspection by IMS are so sensitive that they also allow for detection and measurement of many pressure tube artifacts like, rolls, Burnish Mark, constrictions, ovality etc. Such information is often used for flaw assessment or assessment of channel dimensional data.

## 1. Introduction

During the inspection of CANDU reactor pressure tubes (PT) a variety of PT flaws and artifacts can be observed. Some of these indications have been deliberately targeted for the inspection; some can be seen as “byproduct” of the inspection process. Due to the “filtering” process, in which only indications exceeding certain code and procedure defined reportability levels will be reported in the inspection reports, certain categories and sizes of the indications remain below radar screen as they do not present PT integrity concern at a given time. Such indications are seen by inspection personnel, who use that information for trending, identification of degradation mechanisms and development of new inspection procedures before the indication in this category becomes an issue for the PT integrity assessment. Ultrasonic inspection methods, currently used for the inspection of CANDU reactor PT by OPG-IMS are extremely sensitive to certain categories of flaws. In addition to this, current inspection procedures require sensitivity levels to be even higher (more sensitive) than code requirements in some areas of the pressure tubes. As a result of this the inspection organization has an opportunity to collect high quality data, describing current state of the pressure tube. OPG-IMS has inspected thousands of pressure tubes collecting significant experience in detection, sizing and characterization flaws of various categories and with varying impact on pressure tube integrity. Some of these categories will be discussed in this paper along with detection and sizing/characterization issues specific to such indications.

## 2. Inspection approach

IMS currently operates two full capability inspection systems for the inspection of CANDU reactor pressure tubes:

- Advanced NDE (ANDE)
- Channel Inspection and Gauging Apparatus for Reactors (CIGAR)

Regardless of the inspection system being used the basic PT inspection procedures are essentially the same ensuring good compatibility of results between both systems. The inspection is being performed in three phases:

- System calibration
- Detection scan (called General Helical or GH)
- Sizing and Characterization scans

### *a. System calibration*

In the process of the calibration, system sensitivity level is set using a code defined calibration reflector. For shear wave probes the calibration reflector is a 0.15 mm deep, 6 mm long and 0.15 mm wide rectangular notch. For normal beam probes, sensitivity is established based on the set of flat bottom OD slots.

*b. Detection scan*

During detection scan, indications have to show at some predetermined amplitude levels in order to be regarded as reportable and be selected for sizing and characterization scans. Certain categories of indications will be selected for such scans regardless of their signal amplitude levels based on the procedural requirements.

*c. Sizing and characterization scans*

Detailed sizing and characterization scans will be performed in selected areas allowing for proper sizing and characterization of the indications.

The more detailed description of the inspection system used and inspection approach adopted can be found in another paper by the same author: “Ultrasonic Testing Methods and Procedures for Volumetric and Surface Inspection of CANDU Reactor Pressure Tubes”.

**3. Detectability of indications**

With the code mandated, signal amplitude based approach, as described above, certain categories, shapes and sizes of indications will respond better to the interrogation by the inspection system than others. If the CSA N285.4 code requirements are followed to the letter, indications presenting a corner reflector for the 45° shear wave or direct reflection for the normal beam probes will be the easiest to detect. Thus a code based inspection is biased towards detection of such indications. Indications not offering such reflections may not be detected at levels triggering the reportability requirements thus may not undergo detailed sizing and characterization process.

In order to minimize the effects of such approach, the inspection procedures currently in use by IMS have been enhanced with respect to the minimum requirements specified by the code. Such enhancements include lowering reportability threshold in some areas of the pressure tube and pre-selecting certain categories of indications for detailed sizing and characterization scans regardless of the signal amplitude.

**4. Categories of PT flaws**

There are many ways in which PT flaws can be categorized. The three most commonly applied methods include of categorization include:

- By source
  - a. Manufacturing flaws
  - b. Service induced flaws
  - c. PT artifacts
  - d. Installation flaws
  
- By location
  - a. Inside Diameter (ID)
  - b. Outside Diameter (OD)
  - c. Material

- By code determined severity
  - a. Non reportable
  - b. Reportable (Depth/Amplitude)
  - c. Dispositionable (Depth/Amplitude)

## 5. Review of the most common PT flaws and artifacts – ID indications

### a. Fuel Bundle Bearing Pad Frets (FBBPF)

The FBBPF's result from fretting between fuel bundle support parts and PT material. Such fretting (due to bundle vibrations) is typically not significant with the exception of reactors in 13 bundle configurations. In such reactors, bundle #13, which resides in the Inlet Rolled Joint (IRJ), may vibrate more vigorously, causing accelerated fretting between bundle support pads and PT ID. In addition to this, a phenomenon called Abnormal Fuel Support (AFS) may cause deep and extensive fretting in the Burnish Mark (BM) and Mid Plane (MP) areas.

Indications in this category may or may not respond well to the amplitude based inspection whenever shear wave amplitude based or normal beam probe pulse echo approach is being used. Such indications are fairly sensitive though to the normal beam probe amplitude drop methods and are seen as having very distinct appearance. Sizing and characterization of such indications using normal beam probe B-scans normally do not present major problems. This is not necessarily true in the case of multiple, overlapping residencies and indications affected by the erosion process or uneven surface caused by the irregular shape of the support pads.

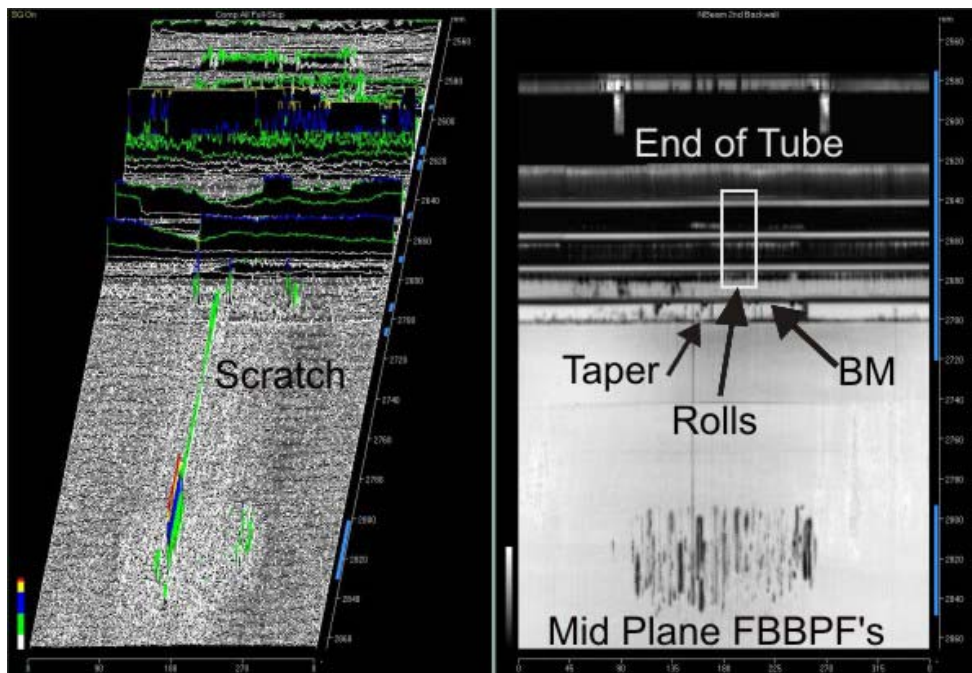


Figure 1 Bundle 13 Mid Plane fretting and Rolled Joint artifacts seen on UT data

*b. Debris frets*

The primary sources of debris fretting are pieces of foreign material trapped between the bearing pad supports and PT ID. Fuel bundle vibrations and movement during refueling operations may cause the foreign material to fret into the PT surface. The debris frets are thought of as resulting from random process and are not expected to possess too many commonalities. Indeed, the experience indicates that there are very few similarities amongst debris frets. They vary greatly in sizes, shapes and types depending on the original source of fretting and the damage process.

Ultrasonically, most of the debris frets respond well to the amplitude based inspection although significant non-uniformity of the response may result from raster scans selected for the detection scan. The tight and deep debris frets often present the challenge for accurate sizing. Use of multiple sizing methods is essential for proper sizing of such indications. Current IMS procedures require use of at least three separate sizing methods for sizing of PT indications. The examinations of debris frets replicated or contained in removed tubes fully justify such approach.



Figure 2 Example of a debris fret (replica)

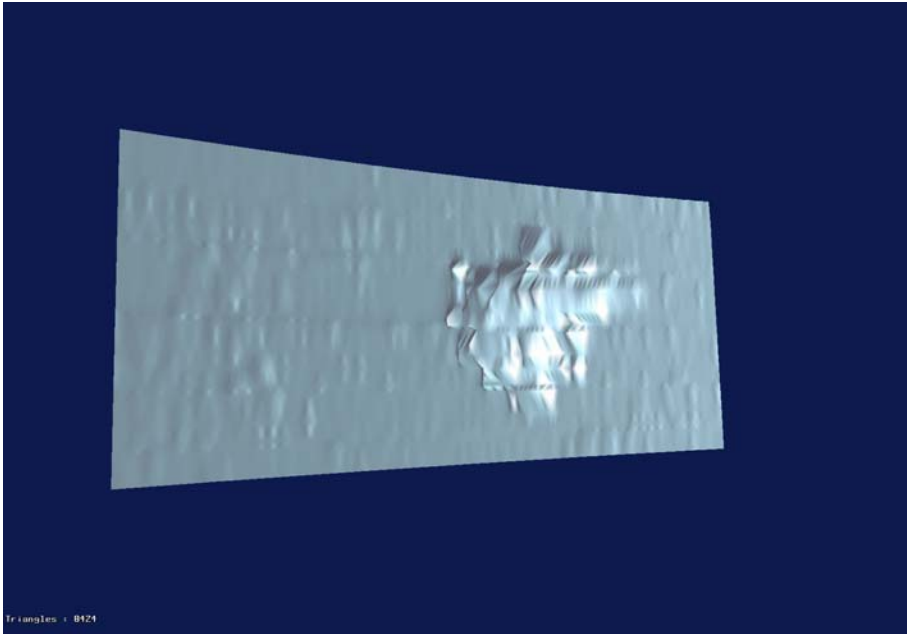


Figure 3 Example of a debris fret image obtained using ultrasonic data

*c. Crevice Corrosion Marks*

Crevice Corrosion (CC) indications result from increasing concentration of LiOH between the bearing pads and pressure tubes under localized boiling conditions. They have been observed in all reactors but some units show higher concentration of CC marks and more accelerated growth. The CC marks tend to cluster in the outlet end and their “intensity” as observed on UT scans seems to correlate with the channel temperature profile.

The most distinctive CC pattern has been observed in Pickering B units.

The CC marks may not be easily detectable based on shear wave; angle beam amplitude based procedure but are easily identifiable on C-scan obtained using normal beam amplitude drop methods. Proper sizing is often challenging due to presence of oxides in the flaw cavity. Sizing methods based on the normal beam probe B-scan may lead to wrong depth sizing as the depth measured will most likely represent the depth of oxide – water interface rather than metal – oxide interface. Replication of such flaws may be similarly affected by oxide presence. Use of Pitch Catch methods becomes critical for sizing of the CC flaws.

*d. Mechanical damage*

Mechanical damage flaws are caused by interaction between fuel bundles, foreign objects, Fuel handling (FH) tooling and maintenance tooling and PT surfaces. The mechanical damage flaws are typically axially oriented and uniform in depth. They tend to respond well to shear wave, angle beam amplitude based inspection and can also be easily seen on the C-scans obtained using normal beam probe amplitude drop methods. In some cases an accumulation of pushed up material can be seen at the end

of the indication. Typical mechanical damage indications are not difficult to detect and size using UT methods.

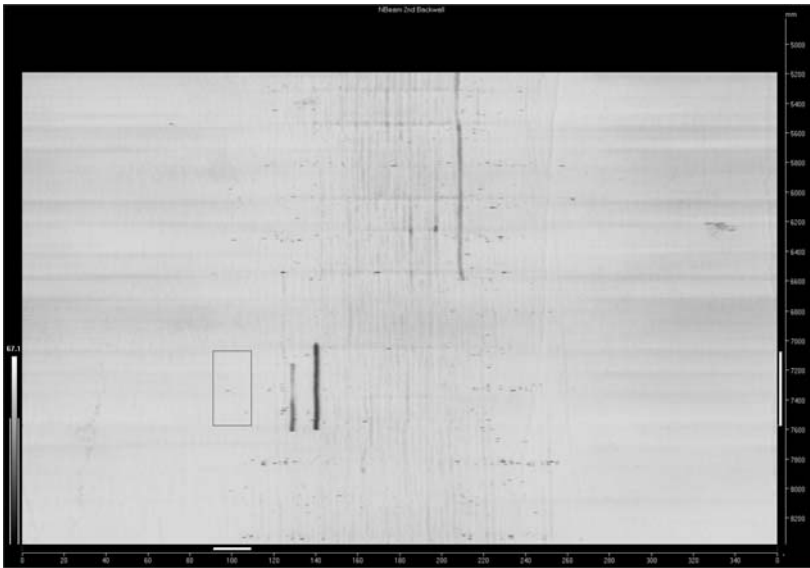


Figure 4 Mechanical damage indication seen on normal beam probe data

*e. Linear indications*

Linear indications are caused by a stringer/inclusion type of indication. They may be open to the surface or subsurface. For indications open to the surface a phenomena called oxide jacking can cause parts of the material to lift and become proud. The linear indications are easily seen by normal beam amplitude drop based C-scans and often show up distinctively on shear wave, angle beam displays.

*f. Scrapes*

Pressure tube scrapes, obtained in a controlled way, present a relatively smooth shape and thus tend not to respond well to the shear wave, angle beam inspection. In some cases, however, the tooling malfunction can cause sharper corners to be introduced into the scrape shape. Such corners tend to respond well to the shear wave signal. Both regular and abnormal scrapes can be seen very well on C-scans obtained using normal beam probe amplitude drop methods.

**6. Review of the most common PT flaws and artifacts - OD indications**

*a. Manufacturing and installation indications*

- RJ scratches
- Installation scratches and gouges
- Sanding scratches
- Coarse grinding marks

These indications typically respond well to both shear wave, angle beam and normal beam amplitude drop methods. The inspection systems currently in use are very sensitive to these kinds of indications. The indications do not usually present any serious integrity concerns. Presence of these indications may cause masking effect for other indications or artifacts of interest as contact or Garter Spring indications.

*b. Pressure Tube to Calandria Tube (CT) contact*

PT to CT contact causes small scratches to appear on the PT OD. Such scratches can usually be seen on both shear wave angle beam displays and normal beam amplitude drop based C-scan displays. They are however, low level indications and may be sometimes masked by system noise. Contact indications will stay in the same place even after the actual contact has been removed.

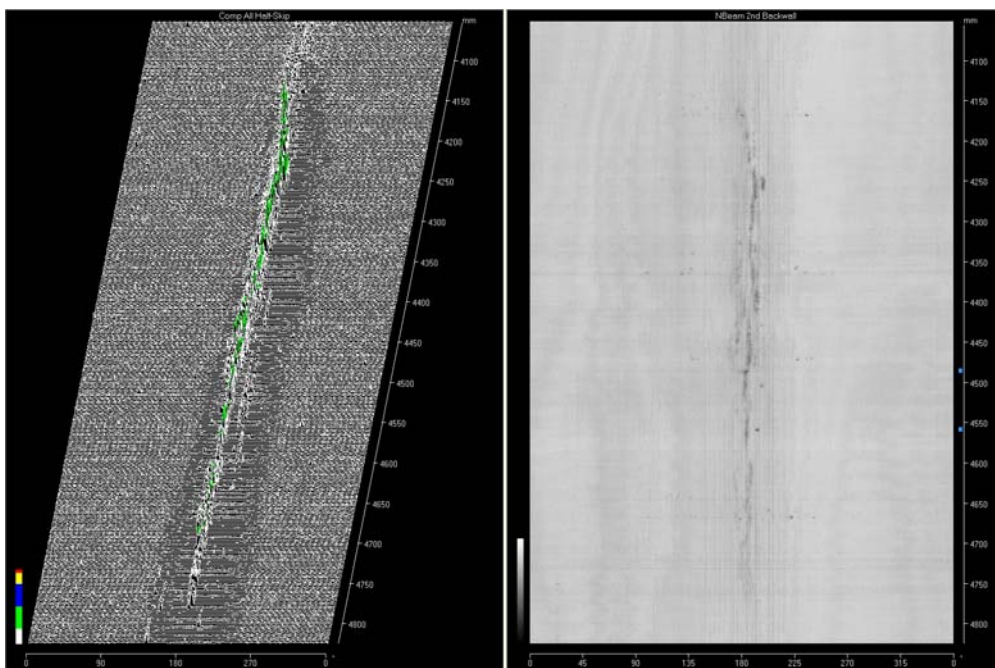


Figure 5 PT to CT contact seen on UT data

*c. Garter Spring (GS) indication*

A Garter Spring presence can be detected by UT methods thanks to the following phenomena:

- In the point of support, A GS can cause an elastic deformation in the PT material. Such deformation can be seen on ultrasonic scan utilizing angle beam, shear wave inspection methods. This indication moves with the spring
- Small scratches may appear as a result of friction between PT and GS. Such scratches do not move with the spring and may indicate past or present position of a spring.
- Pressure tube ovality in a point of support. Such ovality can be seen upon analysis of channel diameter plots. The ovality stays in the same location for a



certain period of time after the spring has been removed. Also, formation of a new ovality may take some time.

## **7. Rolled joint artifacts**

Using UT methods employed by ANDE and CIGAR it is possible to detect a number of pressure tubes artifacts. The most important among them are:

- Burnish Mark
- Rolls
- End of Tube
- Taper

All of these artifacts can be easily identified using normal beam probe amplitude drop C-scans.

In addition to this, presence of water in the rolling grooves can be detected using UT. For a positive determination of the water presence, sizing and characterizations scans have to be performed in the area.

Some of the PT artifacts can be seen in Figure 1.

## **8. Conclusions**

A variety of pressure tube flaws and artifact can be encountered in CANDU pressure tubes. Depending on the inspection procedure used, some flaws may be over or under represented in the reported population. There is a need to adjust inspection procedures for biases caused by code calibration requirements and for actual indications seen a real life. Sizing and characterization of PT indications is a crucial part of the inspection. Multiple sizing methods may have to be used to properly sized and characterize complex indications. OPG/IMS has accumulated significant experience in inspection of pressure tubes, detection and sizing of various indications.