Enclosure A
L-15-091

Examination of Steam Generator Tubes Removed from Beaver Valley Unit 2

(Nonproprietary Version)

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Revision 1

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Prepared for the
FirstEnergy Nuclear Operating Company

Westinghouse

LEGAL NOTICE

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RECORD OF REVISIONS

Revision	Date	Revision Description
0	2/19/2015	Original issue
1	Entered in EDMS	Replaced images in Figure 5-21 and Figure 5-22 with those of better clarity. Adjusted Figure 5-20 to reflect observed cracks in Figure 5-22. Revised text in Section 5.4.3 to describe observed features in Figure 5-21 and Figure 5-22.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

1.1 Background

The U.S. Nuclear Regulatory Commission (NRC) issued Generic Letter 95-05 (GL 95-05) (Reference 1) to give guidance to licensees who may wish to request a license amendment to the plant's technical specifications, and to implement a specific type of alternate steam generator tube repair criterion (ARC). GL 95-05 is applicable specifically to outside diameter stress corrosion cracking (ODSCC) of Alloy 600 steam generator tubing at drilled-hole tube support plate (TSP) locations in Westinghouse-designed steam generators (SGs).

Without the GL 95-05 ARC, plant technical specifications require that flawed tubes be removed from service by plugging or be repaired by sleeving, if the depths of the flaws exceed the repair limit. Prior to implementation of GL 95-05, the repair limit had been 40 percent through-wall (%TW) for Beaver Valley Power Station Unit 2 (BVPS2). The GL 95-05 ARC does not set limits on the depth of ODSCC indications to ensure tube integrity margins; instead, it relies on correlating the eddy current voltage amplitude from a bobbin coil probe with the more specific measurement of burst pressure and leak rate.

The GL 95-05 ARC had been approved for BVPS2 prior to the end of cycle 16 (EOC-16), but had not been implemented. FirstEnergy Nuclear Operating Company (FENOC) had not implemented the ARC due to the relatively low number of bobbin indications at TSP locations that were confirmed by +Point™ [1] to contain axial ODSCC. The GL 95-05 ARC was implemented during the 2R16 outage due to an increase in the number of Distorted Support Indications (DSIs) that were confirmed to contain axial ODSCC.

The 2R17 outage (Spring 2014) represents the second application of the GL 95-05 voltage-based repair criterion to the Beaver Valley Unit 2 SGs. The analysis of the 2R17 outage data is reported in Reference 2.

GL 95-05 notes that the licensee should remove (or pull) two steam generator tube specimens, with an objective of retrieving as many intersections as is practical (a minimum of four intersections), for each plant, either during the plant SG inspection outage that implements the voltage-based repair criteria or during an inspection outage preceding initial application of these criteria. Due to the low voltage response of the BVPS2 DSI population, FENOC received approval from the NRC to forego the tube pull operations until 2R17 (Reference 2).

During the 2R17 outage, FENOC removed two tubes for laboratory examination, each containing a TSP location with confirmed axial ODSCC. Two other TSP locations without confirmed axial ODSCC were included. These tubes were sent to the Westinghouse Churchill Site (WCS) to complete the laboratory examination.

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[1] +Point™ is a trademark of Zetec, Inc.

1.2 Purpose and Scope

The purpose of pulling the tubes was to provide samples for laboratory testing and examinations. The laboratory testing and examinations performed at Westinghouse provided information in support of the GL 95-05 requirements for the voltage-based ARC for axial ODSCC (Reference 1) and approved industry recommendations related to GL 95-05 (Reference 3). The examinations were initiated by FENOC Task Authorization 47320244 (Reference 4) and followed the program of examinations (Reference 5) that was tailored to meet requirements. The examination program included:

- Visual Observations and Photography of As-Received Tubes
- Review of Field NDE
- Laboratory Eddy Current Testing (ECT)
- Dimensional Characterization
- Leak Testing
- Burst Testing
- Post Burst Examinations
- Scanning Electron Microscopy and Energy Dispersive Spectroscopy (SEM/EDS) of Burst Openings
- Defect Metallography
- Tensile Testing
- Bulk Chemistry Analysis
- Microstructure / Microhardness Testing
- Sensitization Testing

Other examinations were conducted as well:

- Measurement of Deposit pH
- SEM/EDS Examination of Deposits

An interim report (Reference 6) was prepared to document the leak test, burst test and morphology (SEM and defect metallography) results and conclusions in support of the 90-day GL 95-05 reporting requirement. In addition, a report documenting eddy current test results was prepared (Reference 7).

This report includes all of the information provided in these reports as well as the results of all the examinations performed on the pulled tubes. All examinations and testing presented in this report were treated as safety-related and are in accordance with the Westinghouse Quality Management System (QMS).

1.3 Steam Generator Description

Beaver Valley Unit 2, operated by FENOC, is a three loop Westinghouse designed pressurized water reactor located in Shippingport, PA. The plant commenced commercial operation in August 1987.

The Westinghouse Model 51M steam generators contain 3376 heat transfer tubes per steam generator. The tubes are mill-annealed NiCrFe Alloy 600 (Alloy 600MA) with a nominal 0.875 inch OD and 0.050 inch wall thickness. The tubes are mounted in 21.25 inches thick (nominal) low alloy steel tubesheets.

Above the tubesheet, most tubes pass through one 0.75-inch thick carbon steel flow distribution baffle (FDB), which is referred to as TSP#1. The tubes pass through the FDB via drilled holes with a diameter of 0.973-0.988 inch.

All the tubes are supported by seven 0.75-inch thick carbon steel tube support plates (TSP), referred to as TSP#2 through TSP#8. The tubes pass through the TSPs via drilled holes with a nominal diameter of 0.891 inch. The diametrical clearance between the TSPs and the tubes (0.016 inch) is considerably less than the clearance between the FDB and the tubes (>0.098 inch).

Table 1-1 provides a summary of the TSP elevations (Reference 8).

1.4 Description of the Beaver Valley Unit 2 Tubes Pulled for Examination

Two tubes were selected by FENOC for removal and laboratory examination, based on the 2R17 outage eddy current examination results and GL 95-05 requirements. Both tube selections were in the "C" steam generator (SG-C).

The tube at Row 19, Column 38 (R19C38) had a 0.62 volt bobbin coil Distorted Support Indication (DSI) at the hot leg TSP#2 (02H) location. This indication was confirmed by +Point.

The tube at Row 24, Column 41 (R24C41) had a 0.47 volt bobbin coil DSI at its 04H location that was confirmed by +Point. It also had a 1.19 volt bobbin coil DSI at its 02H location that was not confirmed by +Point. The pulled tube R24C41 also had a TSP intersection without any bobbin or +Point eddy current indications (03H).

No axial ODSCC indications were profiled due to their limited length and small +Point amplitudes (Reference 9).

Segments from the two tubes were pulled from the hot leg primary side of the tubesheet of SG-C. Tube R19C38 was cut below 03H, pulled through the tubesheet and cut into four segments. Tube R24C41 was cut below 05H, pulled through the tubesheet and cut into seven segments.

Table 1-2 provides a summary of the segments that were delivered to the WCS laboratories. Each segment was placed in its own individual plastic tube, labelled so as to indicate the row, column and section (segment) number. The orientation within the steam generator was also marked.

As each segment was pulled through the tubesheet, it was cut at about a 45° angle so as to aid in tracing the azimuthal orientation from segment-to-segment. A small notch was made at the bottom of most segments to indicate which end of each segment was the bottom and to indicate an azimuthal orientation reference. For the segments from R19C38, the notch is on the side of

the tube that was closest to the periphery. For the segments from R24C41, the notch is on the side of the tube that was closest to the manway.

In comparison with tubes pulled from other plants, the condition of all of the Beaver Valley Unit 2 pulled tube segments from SG-C was good. There were relatively few fresh outer surface scratches/scrapes on the outer surfaces. No significant bends or overt diameter reductions were detected from the pulling operation.

Table 1-1: Support Plate Design Elevations

Location	Distance Above Tube Mouth (inches)
Tubesheet Primary Side / Cladding Surface	0
Tube End (recessed for tube-to-tubesheet weld)	0.04
Cladding-to-Tubesheet Interface (nominal, cladding thickness ≥ 0.15 inch)	0.25
Top-of-Tubesheet (tubesheet thickness = 21.34 / 21.22 inches)	21.47
Center of TSP #1 (FDB)	41.55
Center of TSP #2	71.6
Center of TSP #3	122.1
Center of TSP #4	172.6
Center of TSP #5	223.1
Center of TSP #6	273.6
Center of TSP #7	324.1
Center of TSP #8	374.6

Table 1-2: As-Received Lengths

Tube	Segment	Region Within Segment	Length (in)
R19C38	1	Tubesheet and Top of Tubesheet	25.9
	2	FDB (01H)	31.8
	3	TSP (02H)	25.7
	4	All Freespan	32.4
R24C41	1	Tubesheet and Top of Tubesheet	24.5
	2	FDB (01H)	31.2
	3	TSP (02H)	27.7
	4	All Freespan	33.9
	5	TSP (03H)	32.9
	6	TSP (04H)	32.7
	7	All Freespan	35.6

2.0 RECEIPT INSPECTION

2.1 Verification of Identity and Orientation

The two tubes were cut into a total of eleven segments (see Table 1-2) and provided to the Westinghouse Churchill Site (WCS) in Churchill, Pennsylvania. The segments were provided in individual hard clear plastic tubes. Each segment was clearly identified with the tube row, column, section number and orientation on the clear plastic packaging.

Upon receipt of the tubes in the laboratory, Westinghouse compared labels and segment lengths of each section with tube pull operation documentation. This confirmed that all of the intended sections had been shipped to the lab, that the laboratory personnel understood the labeling and that the orientations of the tubes were understood (up vs. down and azimuthal location). This confirmation is documented in Reference 10.

In this report, the term "segment" generally refers to one of the original eleven lengths of tubing provided to WCS, as listed in Table 1-2. The terms "section" and "piece" may be used interchangeably; each refers to a part cut from its parent tube. A "specimen" generally refers to a sample used in a specific test.

The identification and traceability of sections were maintained in accordance with an established Westinghouse procedure (Reference 11). The designation of each section includes the number of the parent piece. For instance, sections 2A and 2B were cut from piece 2, and sections 2B1 and 2B2 were cut from piece 2B, etc.

For the laboratory examination, the orientation system was based on this bottom end notch. Segments that did not have a notch were given an identifying mark on the bottom end of the segment, at the same azimuthal orientation as on an adjacent segment. The notch was used as the 0° azimuthal reference point; all other azimuthal orientations progressed in the clockwise direction while viewing the tube from the bottom end. See Figure 2-1 for a sketch of the orientation system used in the laboratory. This orientation system was transferred to sections that were cut from these segments by making a similar mark where possible. Unless otherwise stated, this orientation system is used throughout this report.

2.2 Visual Observations

After receipt at the laboratory, segments were visually inspected to document and to identify areas of corrosion, deposits, etc. for potentially more detailed analyses. This examination was conducted with the unaided eye and with a variable magnification stereomicroscope. Observations about tube conditions are discussed below. The general condition of regions of interest: top of the hot leg tubesheet (TTS or TSH), FDB and TSP regions were documented using low magnification digital photographs.

2.2.1 Tube R19C38 – Segment 1 (TTS)

Segment 1 contained the entire tubesheet region, the TTS, and several inches of tubing above the TTS. Segment 1 had the spike used in the tube pulling operation firmly

attached to the inside of the segment through its bottom end. The TTS was located 21.2-inches above the bottom end of Segment 1. The TTS was clearly evident at the elevation, above which, the surface was covered with uniform adherent black deposits; below which was a freshly scraped surface. This demarcation was evident all around the circumference of the segment.

Figure 2-2 shows four views of the TTS region around the circumference of the tube.

A stereomicroscope examination of the area did not identify any evidence of corrosion on the TTS region of R19C38; deposits above the TTS and scrapes below the TTS obscured a direct, unblemished view of the surface. There was no evidence of a sludge collar. Above the TTS, the tube was covered with a thin layer of uniform adherent black deposits. There were several fresh shallow scrapes attributable to the pulling operation, which ran along most of the length of the segment, starting below the TTS and extending above the TTS. Below the TTS, the entire surface was covered with fresh shallow scrapes, typical for a pulled tube and attributable to the tube pulling operation.

There was no evidence of tube installation scratches (which are those that might be created during the manufacturing of the steam generator as a result of passing each tube through the TSPs and FDB). These would appear as narrow scrapes that were covered by deposit.

2.2.2 Tube R19C38 – Segment 2 (FDB)

Segment 2 was covered with a thin uniform layer of adherent black deposit. Circumferential belt polish marks (belt polishing being one of the final steps in the tube manufacturing process) were visible through the deposits in some places. There were several shallow fresh scrapes that ran most of the length of the segment, attributable to the tube pulling operation. Tube installation scratches were not evident.

Segment 2 contained the FDB region. The FDB region was not easily discernable - owing to the relatively large diametrical clearance between the the tube and the FDB, this region differs little in appearance from freespan tubing. The FDB was located 15.3-inches above the bottom of Segment 2, and was identified by calculating its approximate location and then confirming its location by identifying features that would be associated with FDB contact. Using the elevations of the TSPs (see Table 1-1), a cut width of 0.080-inch (the width of the DeWalt cutter used to cut the segments from the parent tube during the pulling operation), and an assumption that ¼-inch of tubing was removed when the tube-tubesheet weld was removed, the centerline of the FDB region was calculated to be 15.3 inches above the bottom of Segment 2. In the vicinity of the 15.3-inch elevation, a circumferential ridge of raised deposit was identified at the 270° orientation, which was an unusual artifact in comparison to the rest of the tube. Presumably, the tube was not perfectly centered in the FDB hole and was closest to the FDB at the 270° orientation, allowing for deposits to accumulate in the crevice between the tube and the FDB at that particular orientation. The presence of the raised deposit feature confirms the calculated location of the FDB.

Figure 2-3 shows four views of the FDB region around the circumference of the tube. Raised deposits are seen at the 270° orientation.

A stereomicroscope examination of the area did not identify any evidence of corrosion on the FDB region of R19C38; most of the tube surface was covered by a thin layer of adherent black deposit which obscured the surface.

2.2.3 Tube R19C38 – Segment 3 (02H TSP)

Segment 3 contained the 02H TSP region. The TSP region was easily identified by unaided visual means as a region of non-uniform deposit. The TSP was centered 13.6-inches above the bottom of Segment 3. Segment 3 was covered with a thin uniform adherent layer of black deposit, except in the region of the TSP and the area just above the TSP region. There were two shallow fresh scrapes that ran most of the length of the segment, attributable to the tube pulling operation.

Figure 2-4 shows four views of the 02H TSP region around the circumference of the tube.

A stereomicroscope examination of the area did not identify any evidence of corrosion on the 02H TSP region of R19C38, although much of the surface was obscured by deposits. The top and bottom of the TSP region had raised deposits around most of the circumference. The TSP region contained areas of raised deposits as well as bare tubing. There was a brownish-tinge to the bare tubing, extending from ~270-0°-90°. The rest of the TSP region had small patches of deposits.

2.2.4 Tube R19C38 – Segment 4 (All Freespan)

Segment 4 was entirely freespan tubing. The entire tube was covered with a thin coat of adherent black deposits over its entire length. There were a few fresh tube pull scratches. There were no other remarkable features on the surface of the segment. Figure 2-5 shows a representative view of Segment 4.

2.2.5 Tube R24C41 – Segment 1 (TTS)

Segment 1 of R24C41 contained the entire tubesheet region, the TTS, and several inches of tubing above the TTS. Segment 1 had the spike used in the tube pulling operation firmly attached to the inside of the tube through its bottom end. The TTS was located 21.1-inches above the bottom end of Segment 1. The TTS was clearly evident as the elevation above which were adherent black deposits and below which was a freshly scraped surface, all around the circumference of the segment. This demarcation was evident all around the circumference of the segment.

Above the TTS, the black adherent deposits were heaviest around the 225° orientation; belt polish marks were not evident. On other parts of the circumference, the deposits were thinner and belt polish marks could be seen.

Figure 2-6 shows four views of the TTS region around the circumference of the tube. In the photos, the yellow color is attributed to the light source. The reddish regions are rust-colored deposits. Since these rust-colored deposits are located within fresh scratches, it is concluded that they were introduced to the tube surface by the tube pulling operation.

A stereomicroscope examination of the area did not identify any evidence of corrosion on the TTS region of R24C41. There was no evidence of a sludge collar. At the TTS, there was a narrow ridge of raised deposits that extended around the circumference. There were several fresh shallow scrapes, attributable to the pulling operation, which ran along most of the length of the segment, starting below the TTS and extending above the TTS. A single tube installation scratch was observed at the 315° orientation. Below the TTS, the entire surface was covered with fresh shallow scrapes; typical for a pulled tube and attributable to the tube pulling operation.

2.2.6 Tube R24C41 – Segment 2 (FDB)

Segment 2 was covered with a thin uniform layer of adherent black deposit. There were several shallow fresh scrapes that ran most of the length of the segment, attributable to the tube pulling operation.

Segment 2 contained the FDB region. The FDB region was not easily discernable - owing to the relatively large diametrical clearance between the the tube and the FDB. This region differs little in appearance from freespan tubing. The FDB was located 16.7-inches above the bottom of Segment 2, and was identified by calculating its approximate location and then confirming its location by identifying features that would be associated with FDB contact. In the vicinity of the 16.7-inch elevation, a narrow, circumferential area of discolored tube surface was identified at the 135°-180° orientation, which was an unusual artifact in comparison to the rest of the tube. Presumably, this is the point where the tube rested against the bottom of the FDB. The presence of the mark was taken as confirmation of the calculated location of the FDB.

Figure 2-7 shows four views of the FDB region around the circumference of the tube. The 180° orientation view shows the FDB-contact mark near the bottom of the photo. The yellow coloration is the light reflecting off of the shiny tube surface features.

A stereomicroscope examination of the area did not identify any evidence of corrosion on the FDB region of R24C41.

2.2.7 Tube R24C41 – Segment 3 (02H TSP)

Segment 3 contained the 02H TSP region. The TSP region was easily identified by unaided visual means as a region of non-uniform deposit. The TSP was centered 15.8-inches above the bottom of Segment 3. Segment 3 was mostly covered with a thin uniform adherent layer of black deposit, except in the region of the TSP and several inches of area just below the TSP region that may have been scraped off during the tube pulling operation. One light tube installation scratch was observed at the 270° orientation.

Figure 2-8 shows four views of the 02H TSP region around the circumference of the tube.

A stereomicroscope examination of the area did not identify any evidence of corrosion on the 02H TSP region of R24C41, although some of the surface was obscured by deposits. The top and bottom of the TSP region had patches of raised deposits around most of the circumference. The rest of the TSP region also had small patches of deposits, but large portions of the TSP region were free of deposits.

2.2.8 Tube R24C41 – Segment 4 (All Freespan)

Segment 4 was entirely freespan tubing. There was a thin coat of adherent black deposits up to about 21-inches from the bottom of the segment; above this, the tube surface was black, but had a shiny appearance. There were a few light, fresh tube pull scratches. There were no other remarkable features on the surface of the segment. Figure 2-5 shows a representative view of Segment 4.

2.2.9 Tube R24C41 – Segment 5 (03H TSP)

Segment 5 contained the 03H TSP region. The TSP region was easily identified by unaided visual means as a region of non-uniform deposit. The TSP was centered 4.8-inches above the bottom of Segment 5. Segment 5 was mostly covered with a uniform adherent layer of black deposit, except in the region of the TSP and a small region just above the TSP. Several light tube pull scratches were observed.

Figure 2-10 shows four views of the 03H TSP region around the circumference of the tube.

A stereomicroscope examination of the area did not identify any evidence of corrosion on the 03H TSP region of R24C41, although nearly the entire surface was obscured by deposits. The top and bottom of the TSP region had patches of raised deposits around most of the circumference.

2.2.10 Tube R24C41 – Segment 6 (04H TSP)

Segment 6 contained the 04H TSP region. The TSP region was easily identified by unaided visual means as a region of non-uniform deposit. The TSP was centered 23.0-inches above the bottom of Segment 6. Segment 6 was mostly covered with a uniform adherent layer of black deposit, except in the region of the TSP. Several light tube pull scratches were observed.

Figure 2-11 shows four views of the 04H TSP region around the circumference of the tube.

A stereomicroscope examination of the area did not identify any evidence of corrosion on the 04H TSP region of R24C41, although much of the surface was obscured by deposits. The top and bottom of the TSP region had patches of raised deposits around most of the circumference. In several areas of the bare tubing within the TSP region, the tube surface

has a brownish color. At the 90°-180° orientations, spots of brown were observed on top of the deposits.

2.2.11 Tube R24C41 – Segment 7 (All Freespan)

Segment 7 was entirely freespan tubing. There was a thin coat of adherent black deposits over the entire length. There were a few light, fresh tube pull scratches. There were no other remarkable features on the surface of the segment. Figure 2-12 shows a representative view of Segment 7.

2.3 Dimensional Characterization

The as-received lengths of the segments provided to the laboratory are summarized in Table 1-2. After completion of the initial visual inspection and documentation of the as-received condition of the tube segments, a series of diameter measurements were made to characterize the dimensions in the regions of interest.

Prior to dimensional characterization, the portions of tubing containing the TTS and TSP regions were cut into manageable lengths of 12-inches. This was done for ALARA purposes, as well as in preparation for eddy current testing, leak screening and burst testing. The TTS and TSP regions were centered as best as possible within the 12-inch length of its section. Ends of the tube sections were squared–off and deburred.

Following sectioning, dial caliper (Reference 12) measurements were made of the outer diameter of the TTS and TSP regions to obtain a profile of the diameter. These measurements were made to characterize the presence of any ovalization or denting that may have been present. Measurements were made every 1/8-inch, starting an inch below the region and extending to an inch above the region. Measurements were made every 45° around the circumference at each elevation.

2.3.1 Diameter Profile of R19C38 Regions

Figure 2-13 presents a profile of the diameter in the TTS region of R19C38. The vertical axis (on the left) provides the diameter, the horizontal axis (on the bottom) provides the distance from the TTS (with the TTS in the middle of the axis at the 0.000-inch mark), and the remaining axis (on the right) provides the azimuthal orientation (using the orientation system portrayed in Figure 2-1). Diameters are color coded in 5 mil increments, as is shown in the legend, to help visualize the profile.

Figure 2-13 shows that deposits and scrapes partially affected the tube diameter measurements. The wide tube pull scrape at the 0° orientation (see Figure 2-2) was responsible for reduced diametrical measurements at the 0°/180° orientation, both below and above the TTS. There may have been some mild ovalization of the tube in the vicinity of the TTS (likely from the tube pull operation) resulting in a maximum diameter at the 45°/225° orientation, both below and above the TTS. The bottom of the expansion transition is evident at the 0-inch elevation, and the expansion transition is shown to be 1/8-inch to ¼-inch in length. There was no sign of denting at the R19C38 TTS.

Figure 2-14 presents a profile of the diameter in the FDB region of R19C38. Deposits partially interfere with the tube diameter measurements. The wide tube pull scrape at the 0° orientation (see Figure 2-3) was responsible for reduced diametrical measurements at the 0°/180° orientation along the entire measured length. A scratch with raised edges at about the 145° orientation caused slightly elevated diameter measurements. In general, the FDB region diametrical profile is indistinguishable from the freespan tubing above and below the region.

Figure 2-15 presents a profile of the diameter in the 02H TSP region of R19C38. The TSP region is shown as a region with elevated deposits. Denting was not evident from the diametrical measurements, but if present, may have been obscured by deposits. The deposits in the ½-inch region above the top of the TSP were, on average, about 3 mils thicker than the deposits immediately below the bottom of the TSP.

2.3.2 Diameter Profile of R24C41 Regions

Figure 2-16 presents a profile of the diameter in the TTS region of R24C41. As there were few deposits above the TTS, the surface is relatively unobscured. The bottom of the expansion transition is evident at the 0-inch elevation, and the expansion transition is shown to be 1/8-inch to ¼-inch in length. There was no sign of denting at the R24C41 TTS.

Figure 2-17 presents a profile of the diameter in the FDB region of R24C41. Deposits partially interfere with the tube diameter measurements. In general, the FDB region diametrical profile is indistinguishable from the freespan tubing above and below the region.

Figure 2-18 presents a profile of the diameter in the 02H TSP region of R24C41. As Figure 2-8 shows, there were raised deposits at the top and bottom of the TSP region, but large parts of the TSP region were free of deposits. The deposits in the ½-inch region above the top of the TSP were, on average, about 5 mils thicker than the deposits immediately below the bottom of the TSP. The diametrical measurements show a region of reduced diameter at the centerline of the TSP region at the 45°/225° orientation, although the entire centerline of the TSP had a diameter that was about 2-3 mils less than the baseline diameter (see the region above the TTS in Figure 2-16). Metallography identified three short axial cracks with a maximum depth of 14.2% throughwall at the 160° orientation and two short axial cracks with a maximum depth of 10.7% throughwall at the 340° orientation. The 160°/340° cracks are approximately orthogonal to the reduced diameter at 45°/225°. It is possible that tube diameter compression caused by corrosion products in the vicinity of the 45°/225° orientation would introduce tensile stresses to the outer surface of the tube 90° around the circumference, although there was no corresponding increase in diameter measured at the 135°/315° orientation. It is possible that the cracks identified in the 02H TSP region of R24C41 were caused by in-service denting.

Figure 2-19 presents a profile of the diameter in the 03H TSP region of R24C41. As Figure 2-10 shows, almost the entire region was covered with deposits, which were 5-9 mils thick. Since the tube-TSP drilled hole diametrical clearance is a nominal 16 mils, it seems that a significant fraction of the crevice deposits were retained on the 03H TSP region. Any sign of denting was covered by deposit.

Figure 2-20 presents a profile of the diameter in the 04H TSP region of R24C41. As Figure 2-11 shows, most of the region was covered with deposits, except in the vicinity off the 45° orientation. The deposits, where present, were 4-8 mils thick. Any sign of denting was covered by deposit.

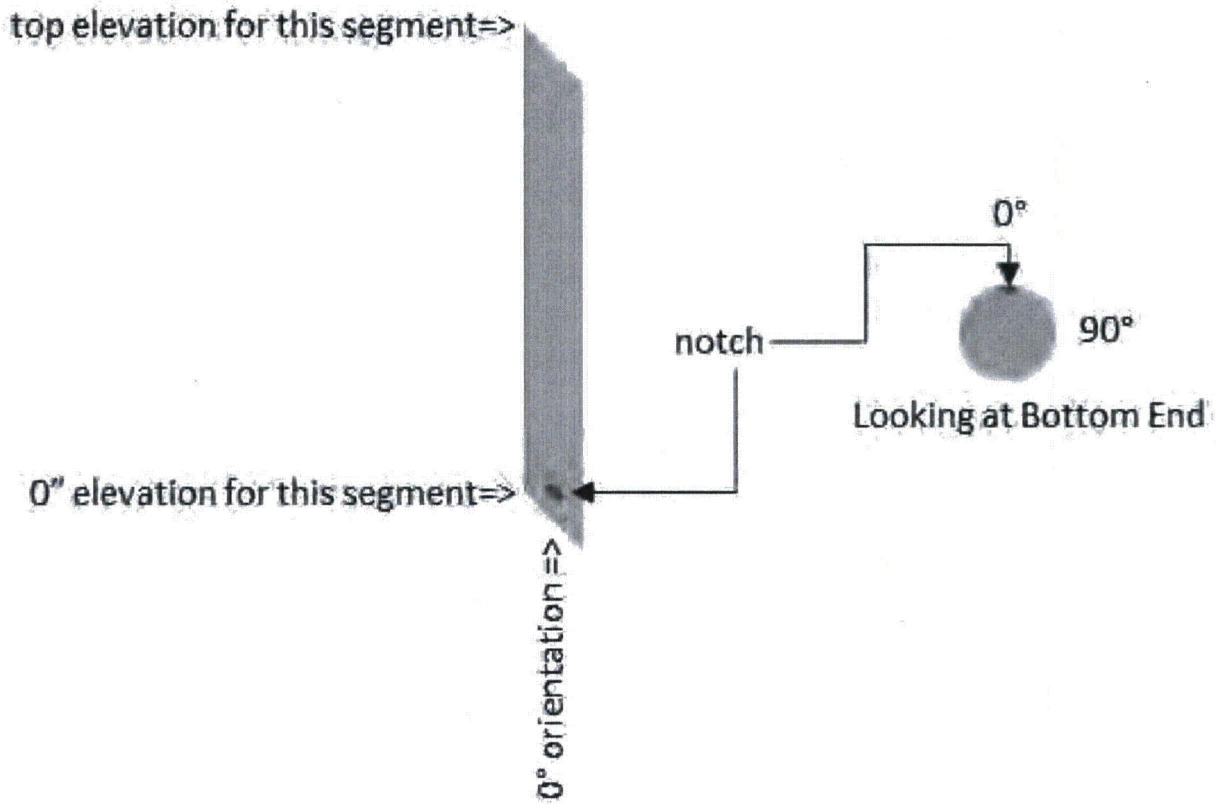


Figure 2-1: Orientation System Used in the Examination

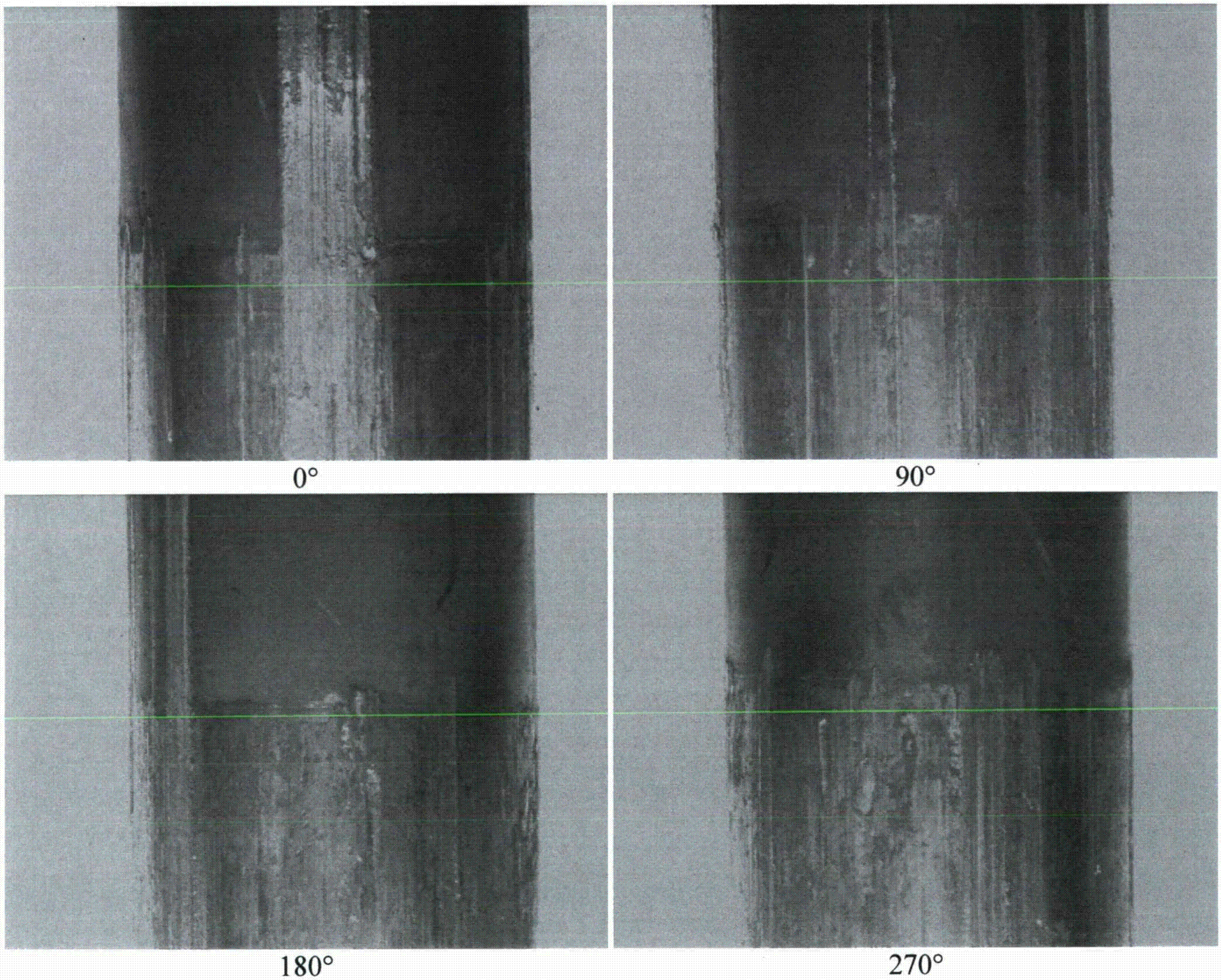
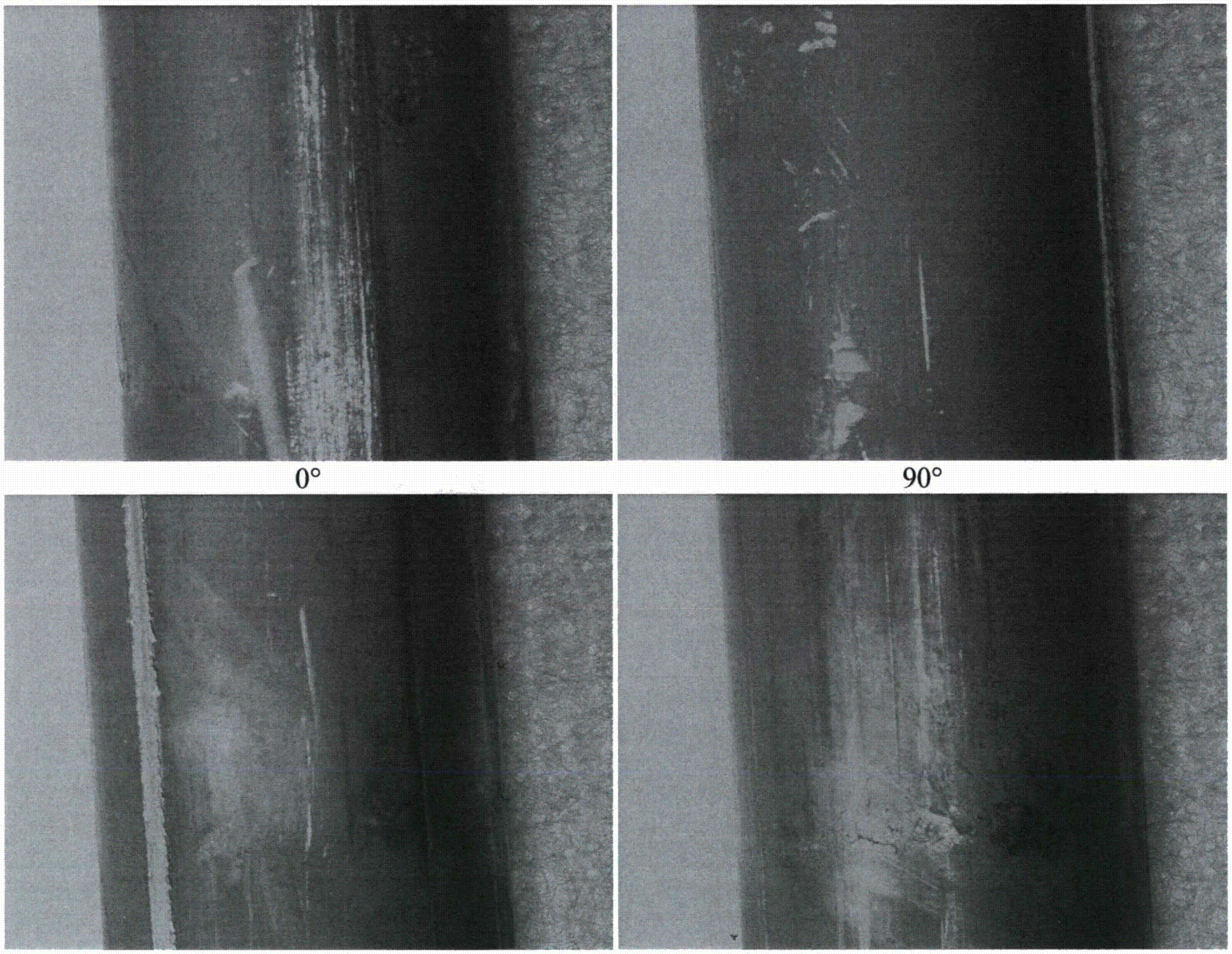


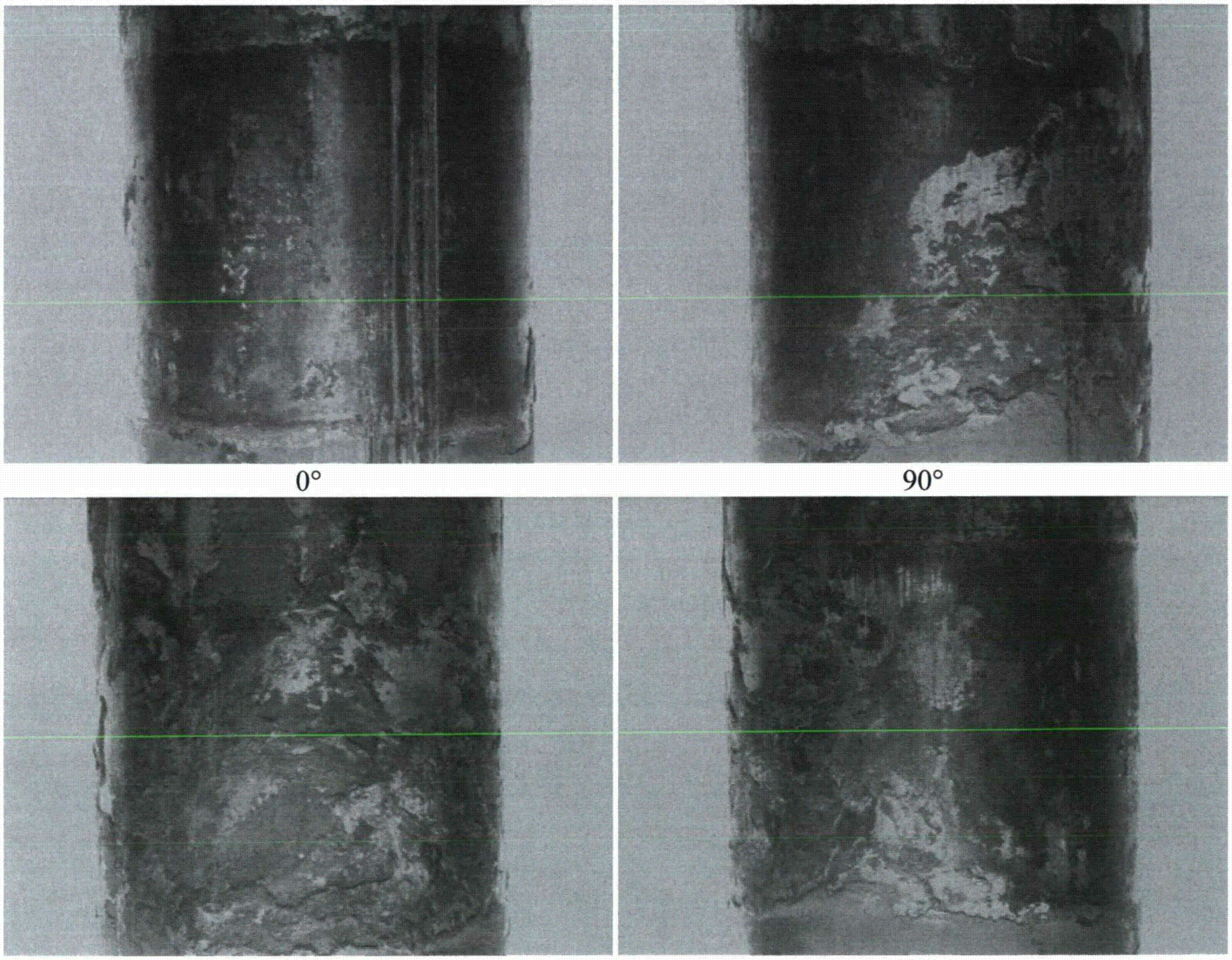
Figure 2-2: As-Received Views of R19C38 TTS Region



0° 90°

180° 270°

Figure 2-3: As-Received Views of R19C38 FDB Region

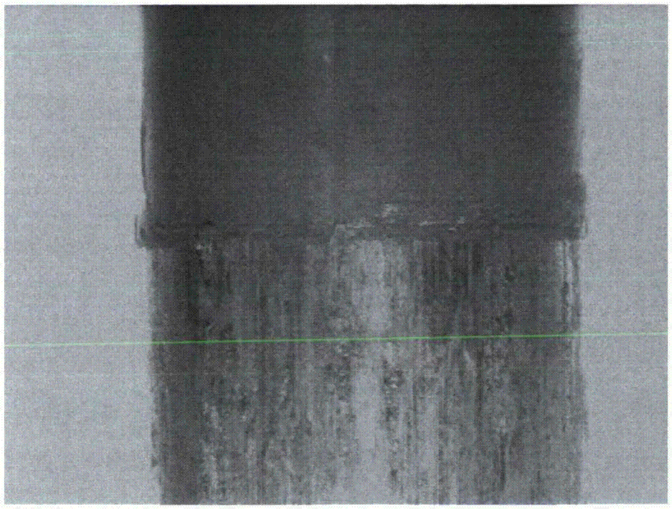


0° 90°

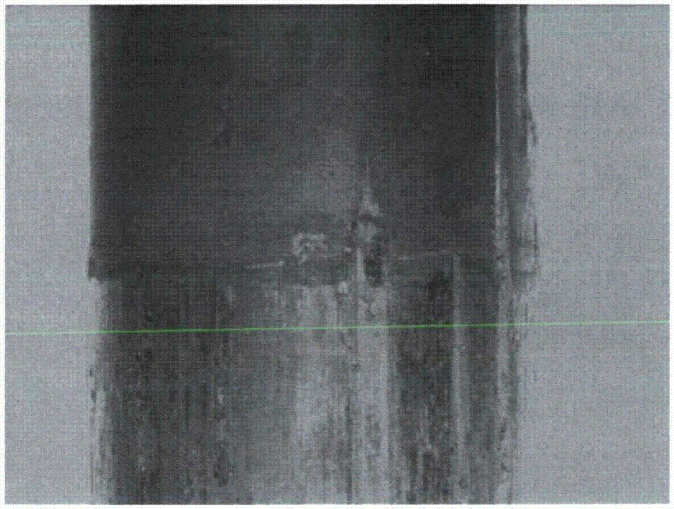
180° 270°

Figure 2-4: As-Received Views of R19C38 02H TSP Region

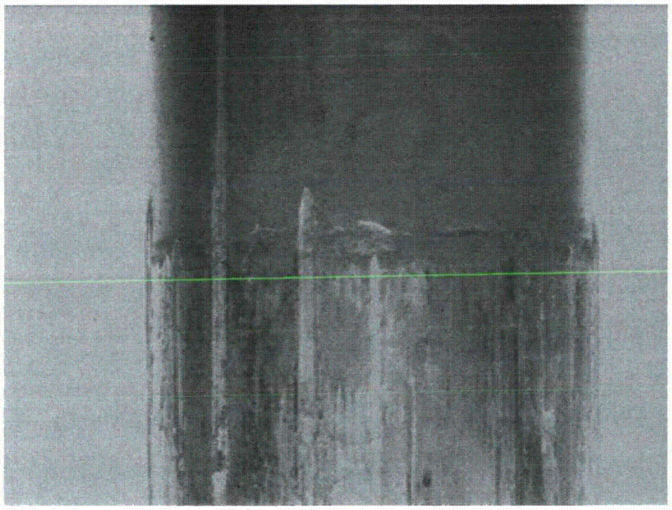
Figure 2-5: As-Received Representative Views of R19C38 Freeespan Segment 4



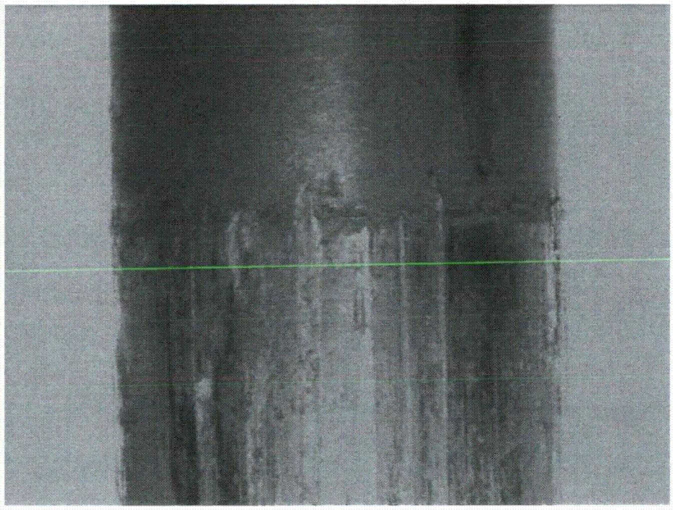
0°



90°



180°



270°

Figure 2-6: As-Received Views of R24C41 TTS Region

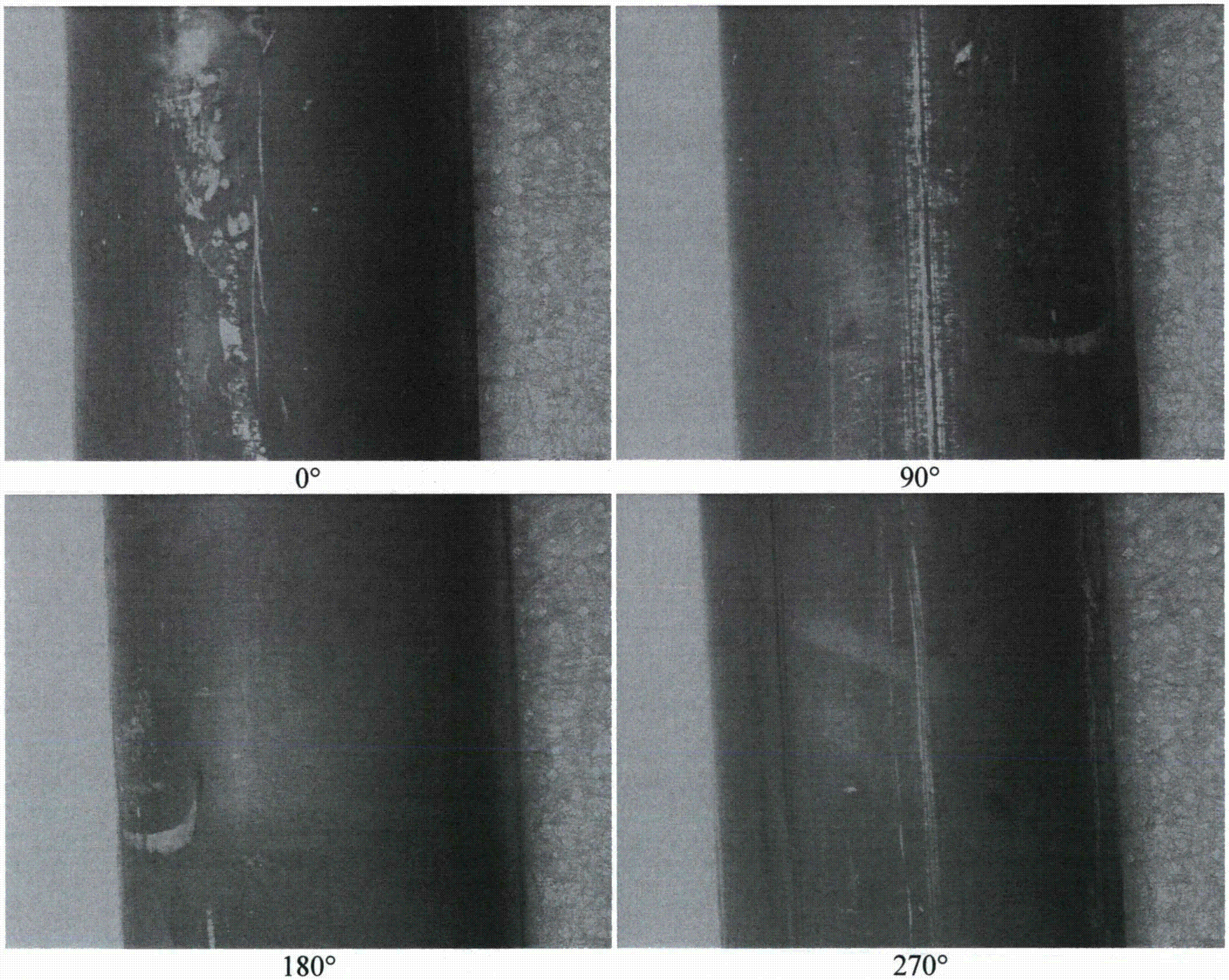


Figure 2-7: As-Received Views of R24C41 FDB Region

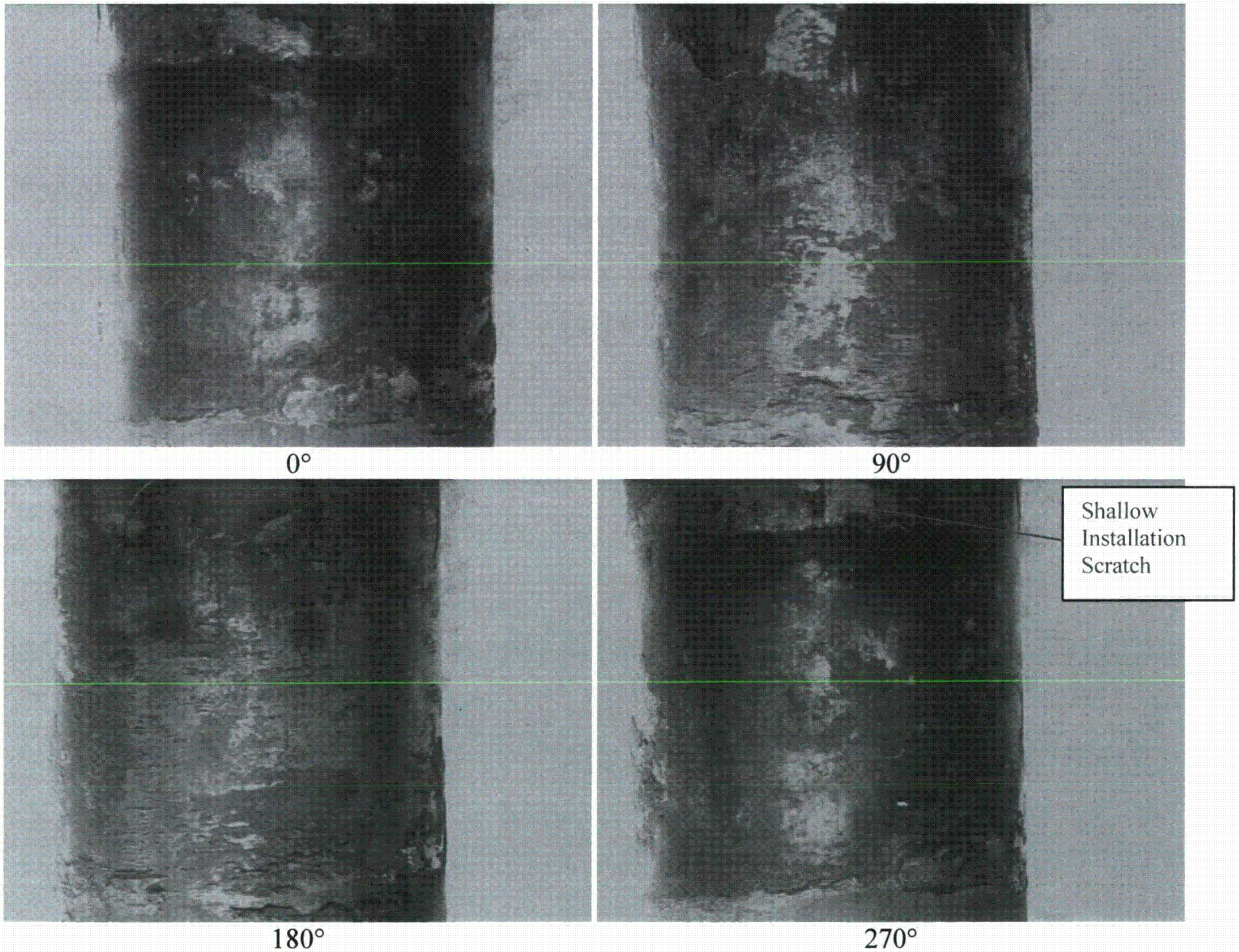


Figure 2-8: As-Received Views of R24C41 02H TSP Region

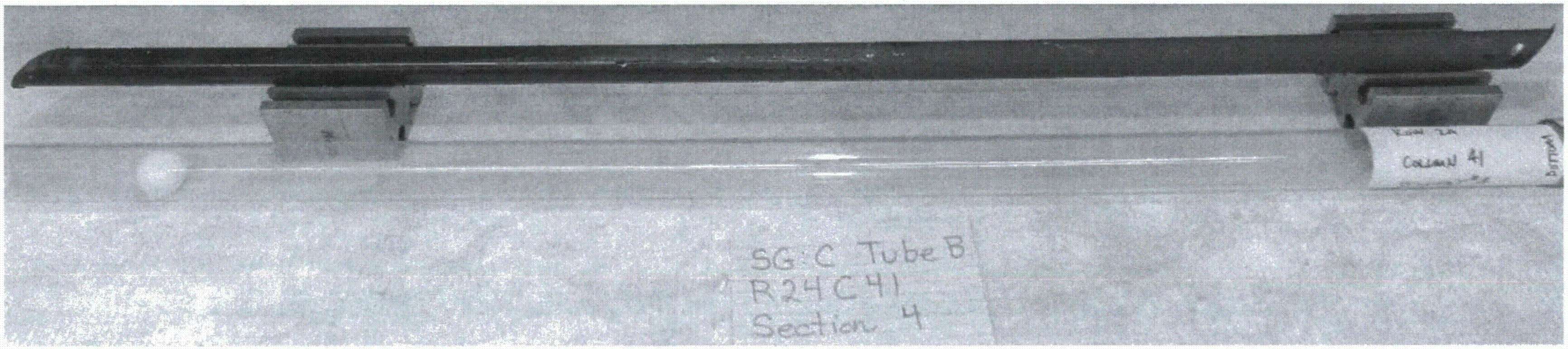


Figure 2-9: As-Received Representative Views of R24C41 Freeespan Segment 4

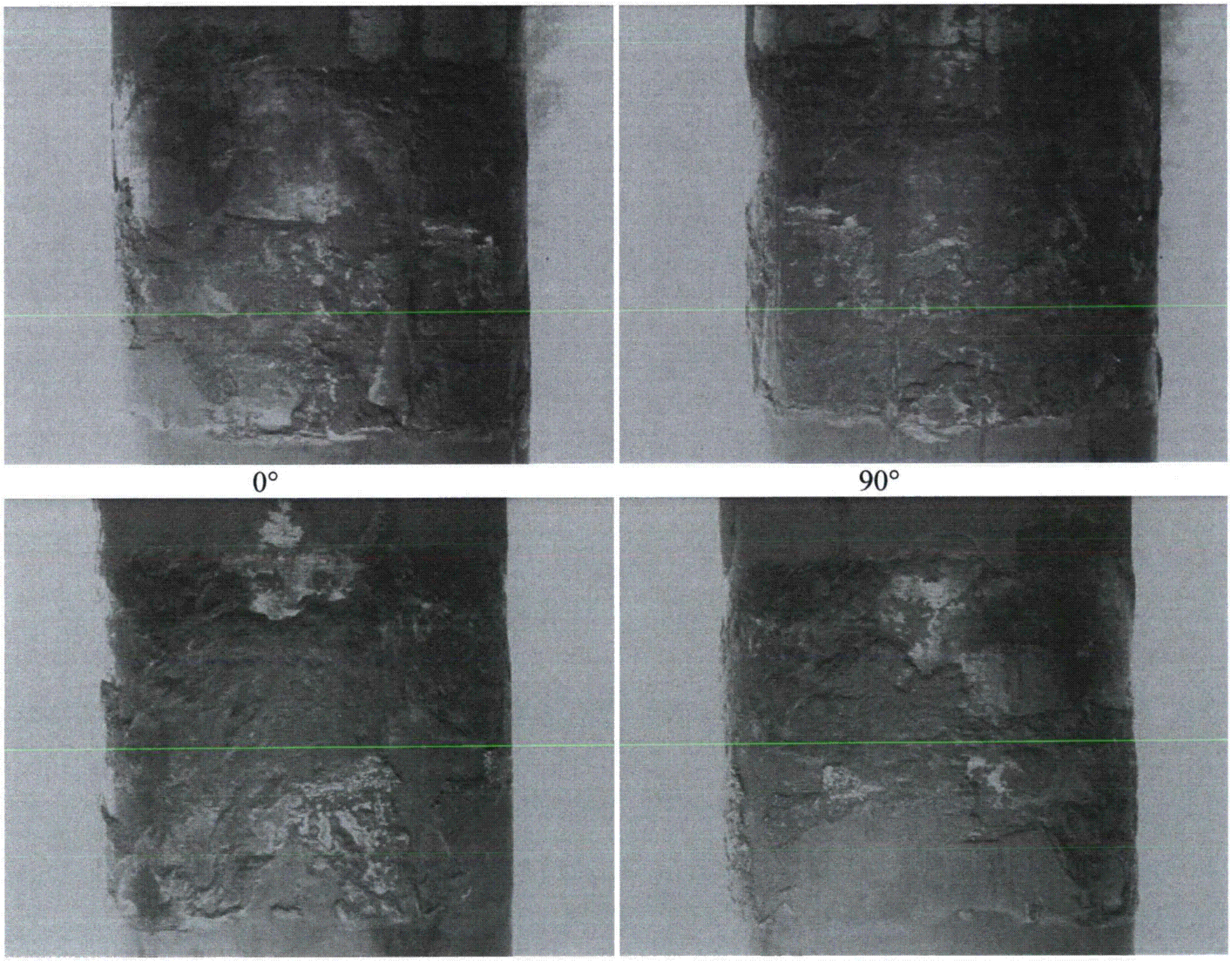


Figure 2-10: As-Received Views of R24C41 03H TSP Region

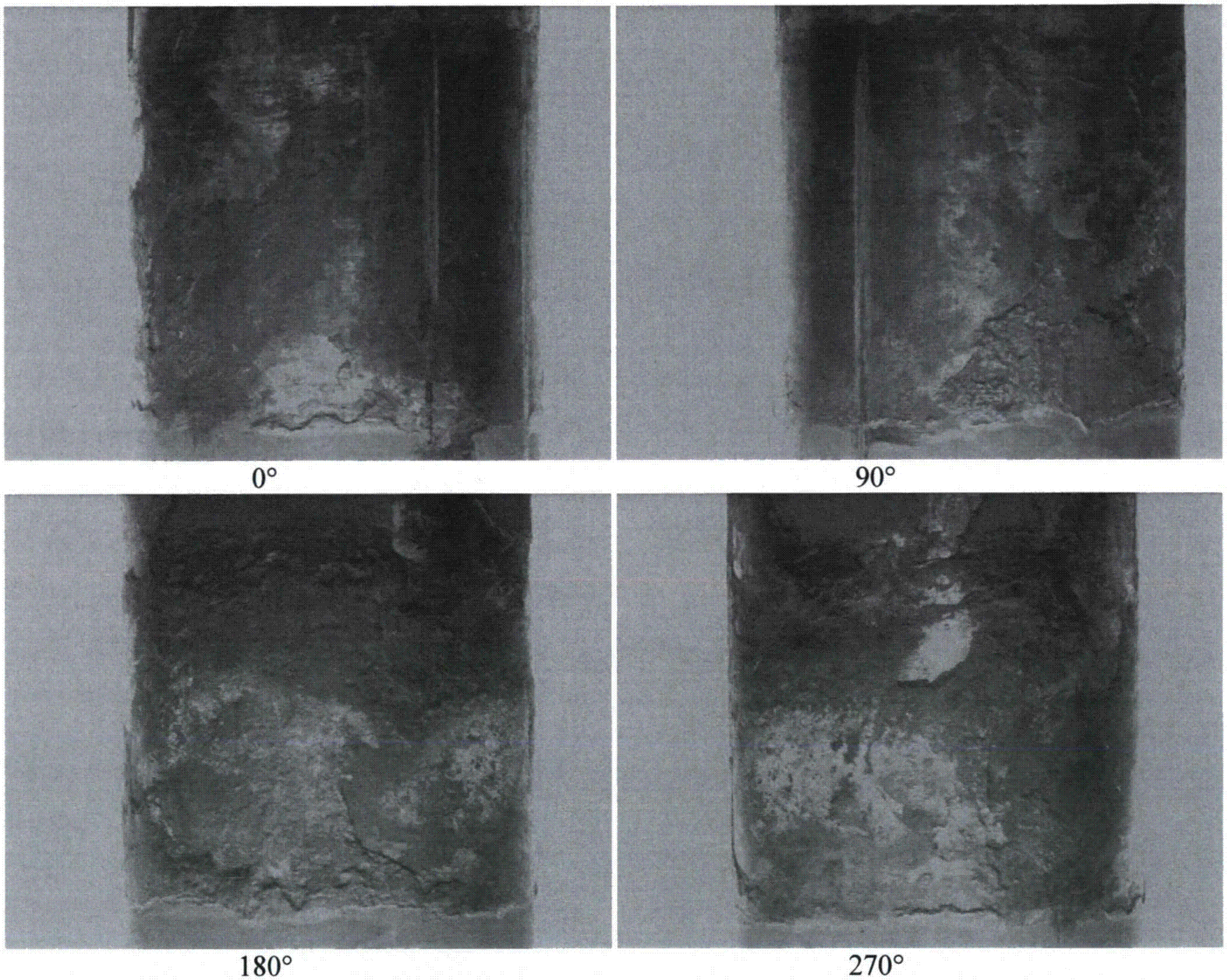


Figure 2-11: As-Received Views of R24C41 04H TSP Region

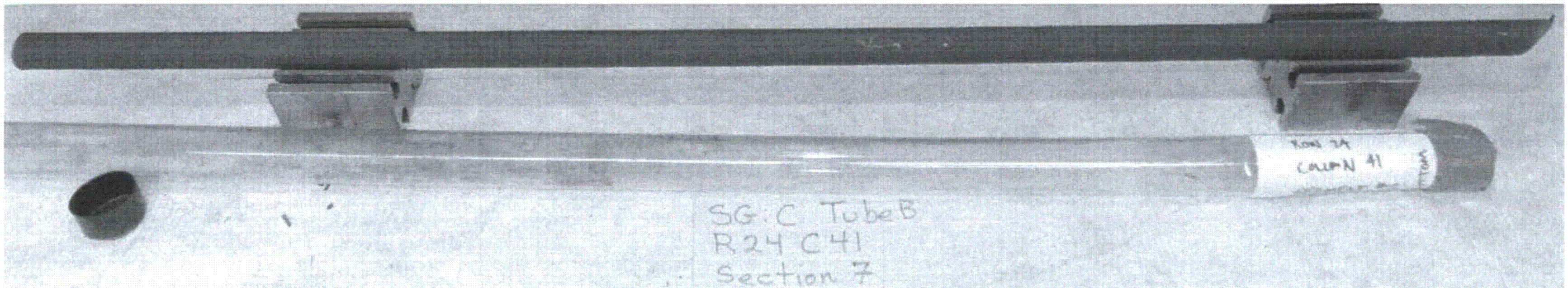


Figure 2-12: As-Received Representative View of R24C41 Freeespan Segment 7

a,c,e

Figure 2-13: Diameter Profile of TTS Region of R19C38, Showing the Expansion Transition

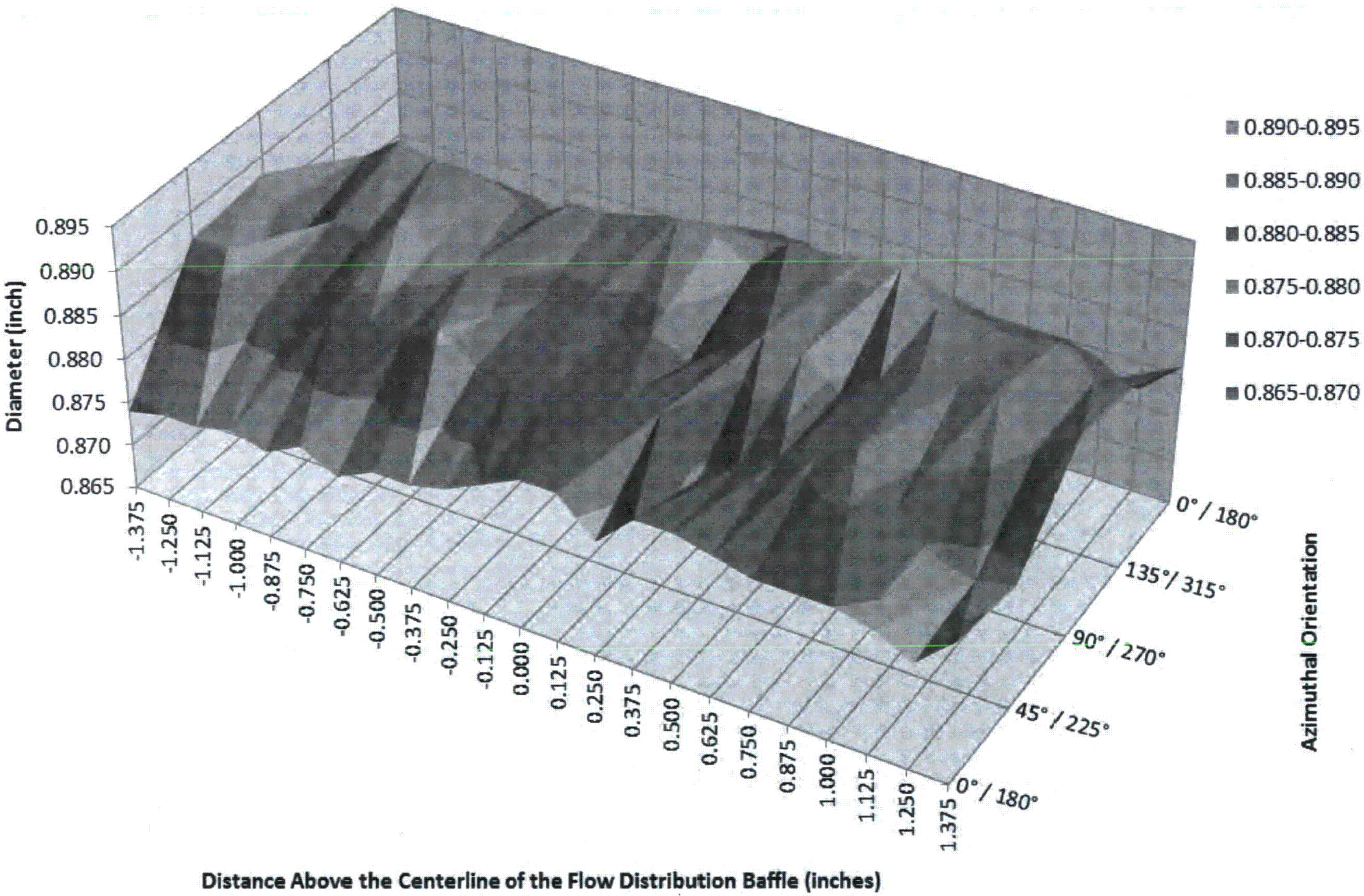


Figure 2-14: Diameter Profile of FDB Region of R19C38

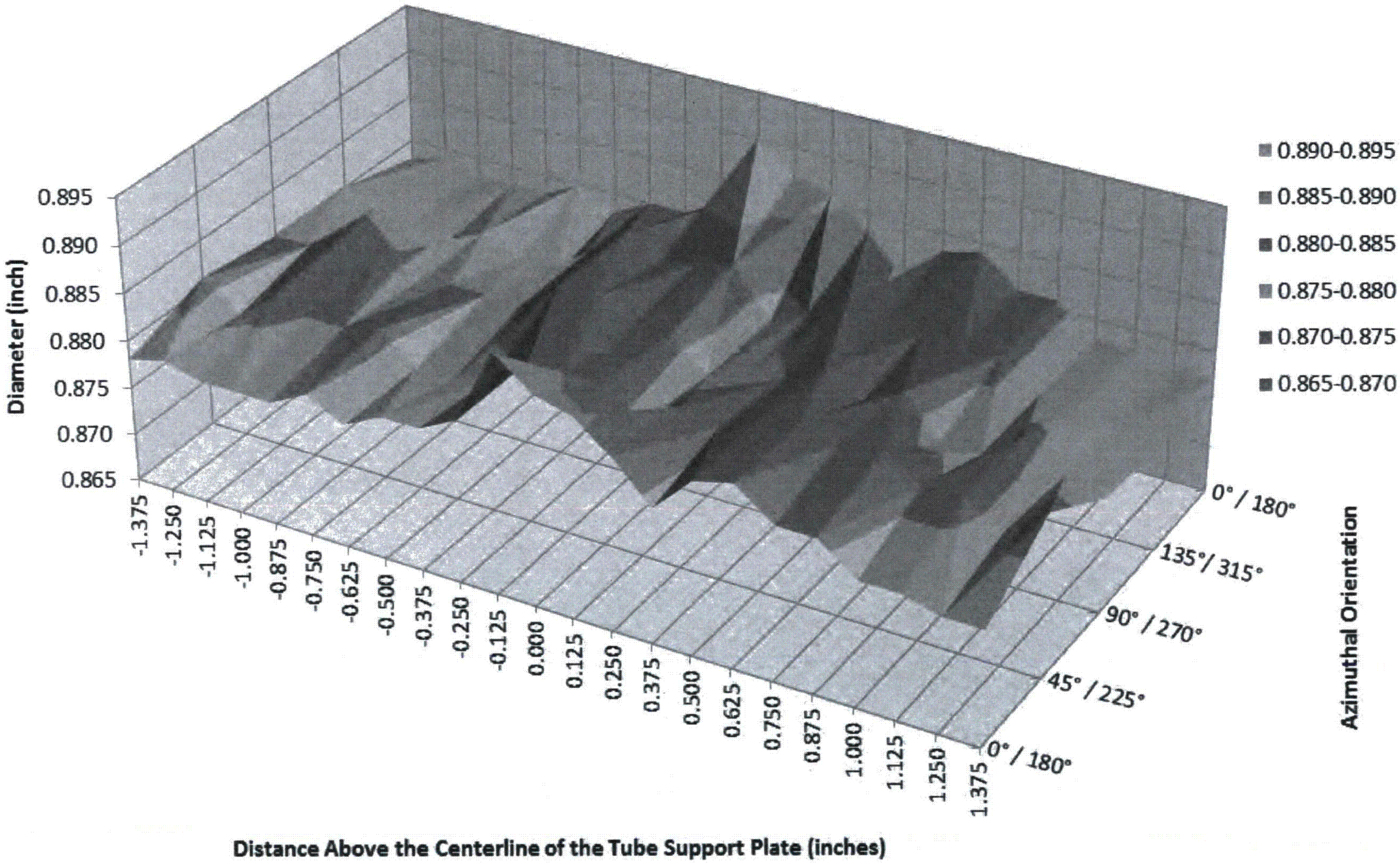


Figure 2-15: Diameter Profile of 02H TSP Region of R19C38

a,c,e

Figure 2-16: Diameter Profile of TTS Region of R24C41, Showing the Expansion Transition

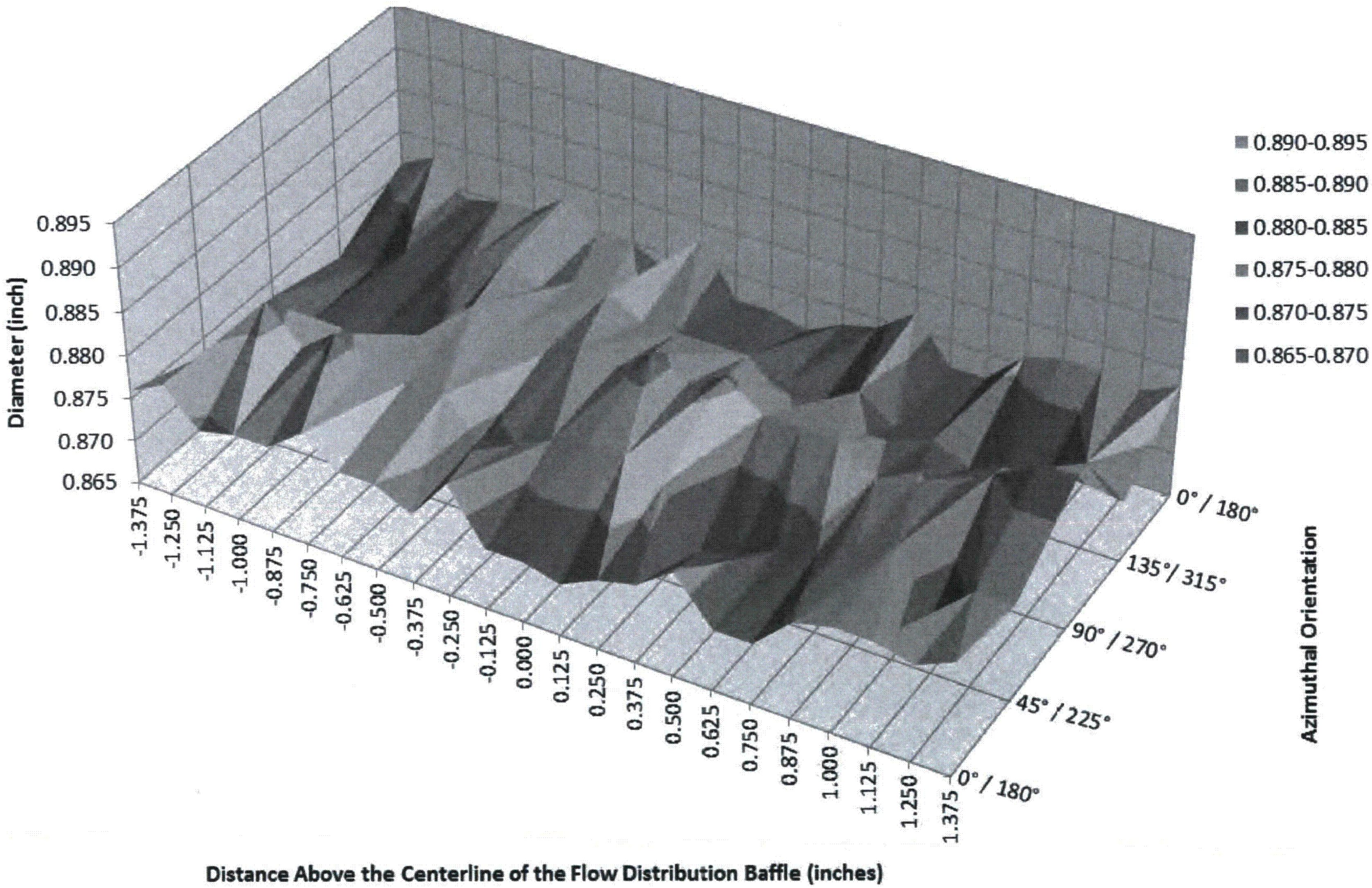


Figure 2-17: Diameter Profile of FDB Region of R24C41

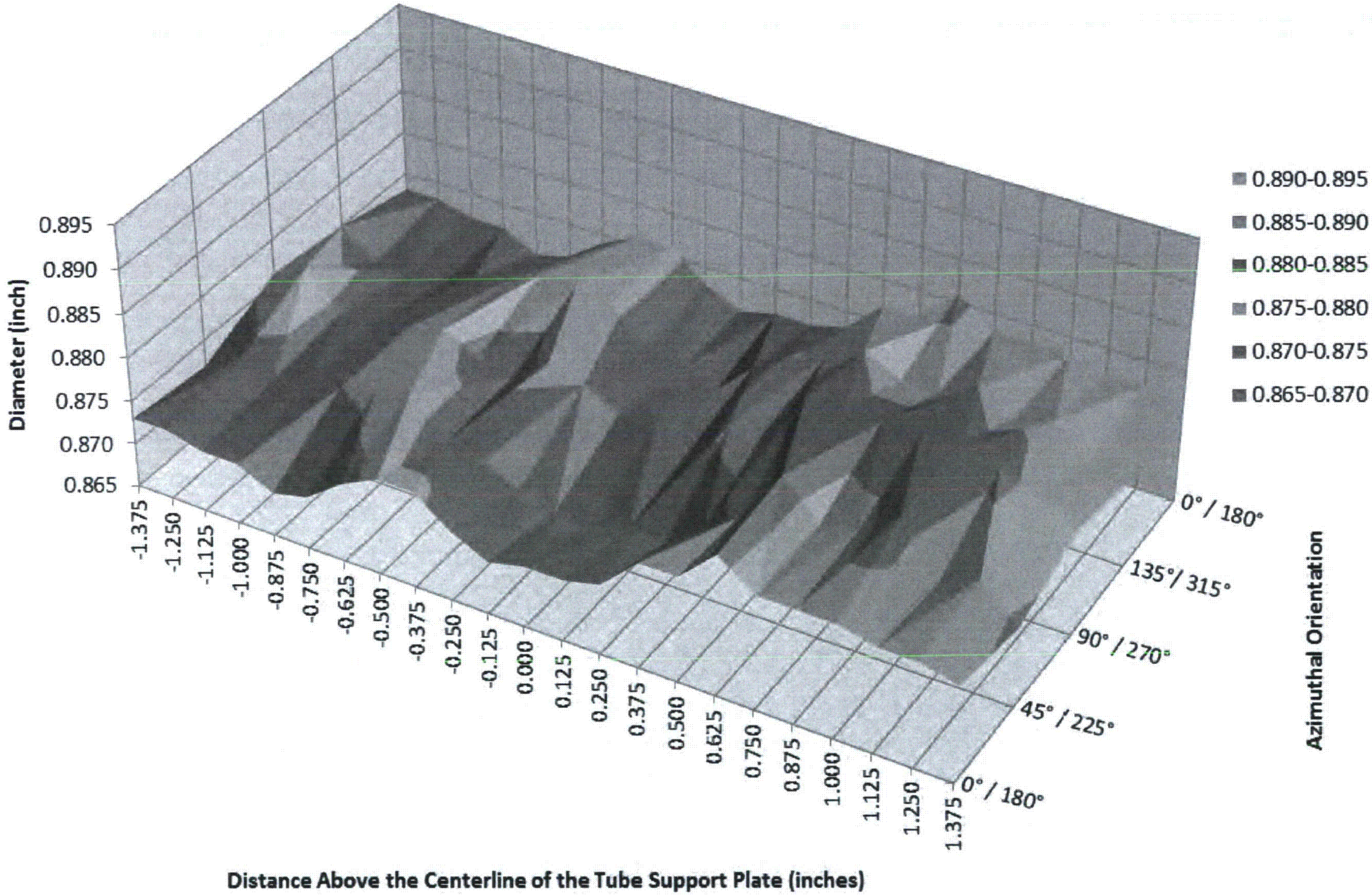


Figure 2-18: Diameter Profile of 02H TSP Region of R24C41

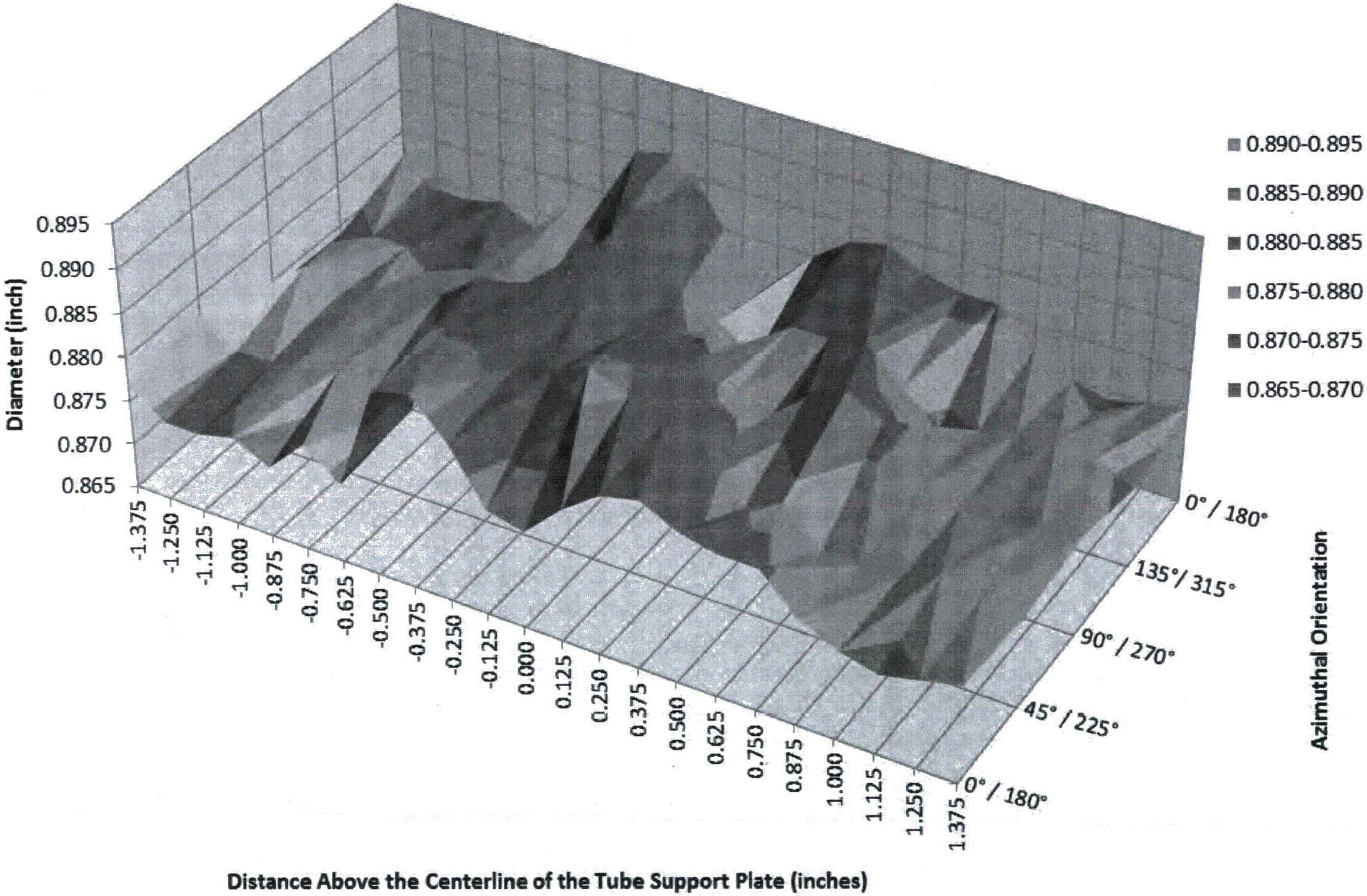


Figure 2-19: Diameter Profile of 03H TSP Region of R24C41

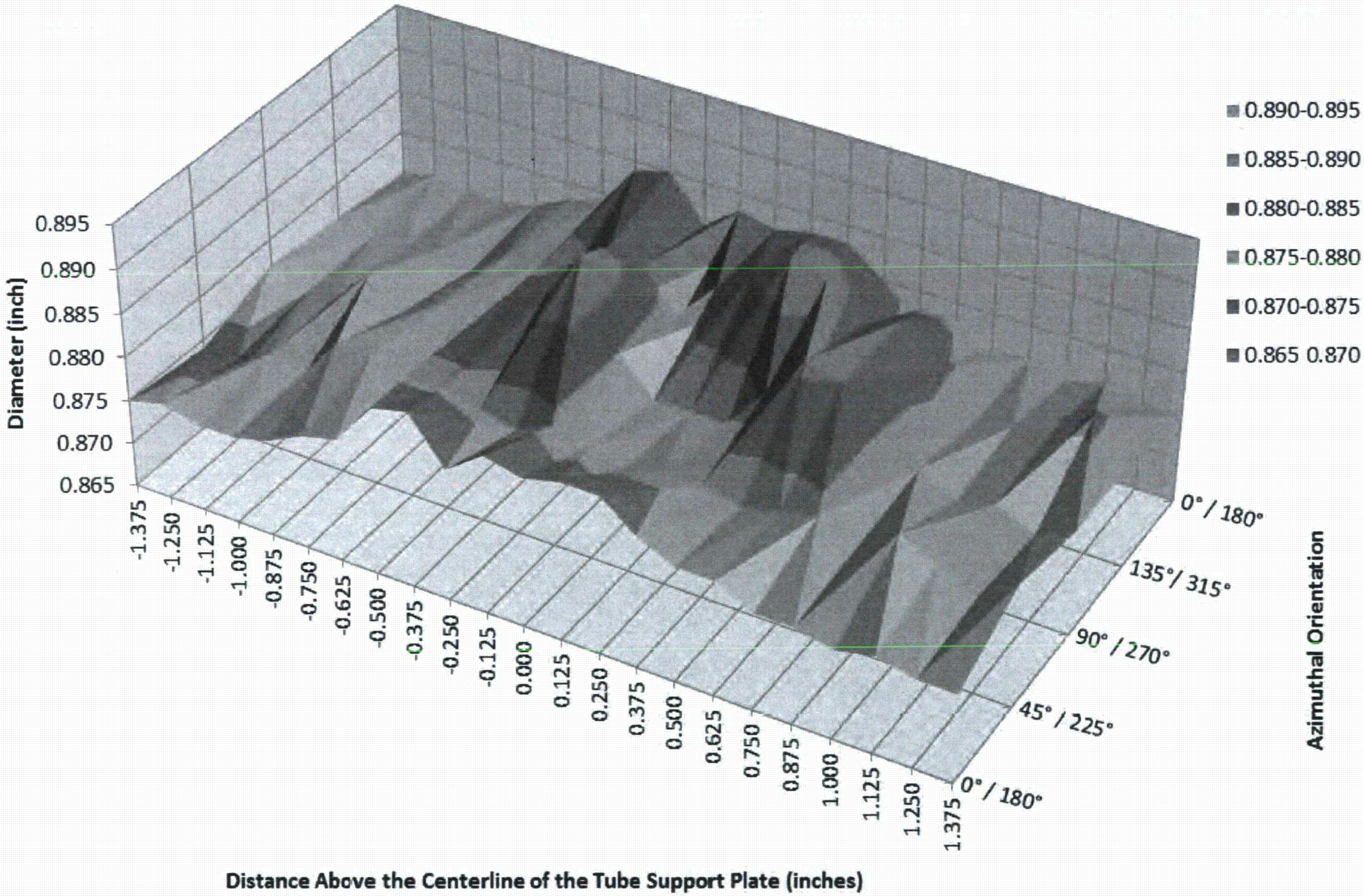


Figure 2-20: Diameter Profile of 04H TSP Region of R24C41

3.0 EDDY CURRENT TEST INSPECTION

3.1 Introduction

Six sections, each approximately 12-inches long, were shipped to the Westinghouse Waltz Mill Site from WCS to have eddy current testing (ECT) performed. As was noted in Section 2.3, the TTS and TSP regions were centered as best as possible within the 12-inch length of its section. Table 3-1 lists the sections. Two sections were from R19C38 that included the TTS and 02H TSP locations. Four sections were from R24C41 that included the TTS, and the 02H, 03H and 04H TSP locations. There were three different test types performed on all six sections: bobbin, +Point and Ghent. The analysis was performed at the Waltz Mill Remote Data Eddy Current Data Analysis Center (REDAC). Non-destructive examination (NDE) certifications for personnel involved with the eddy current acquisition and analysis are included in Appendix A of Reference 7.

3.2 General Laboratory Acquisition and Analysis

For all tests performed, the appropriate standard was tested at the beginning and end of each data set (REEL). A message was recorded prior to the testing of each section and test type indicating the identification of the section and the orientation that the sections were tested. The data for each test was monitored (in real time) by the Level III qualified data analyst (QDA) to ensure data quality. The analysis and setups for all three techniques (Bobbin, +Point probe and Ghent) were performed in the REDAC and in accordance to applicable requirements documented in References 13 through 17. A piece of aluminum backed tape was used to create an "L" shape which is distinguishable to rotating type probes. The "L" shape was located on each section as documented in Table 3-1. The circumferential arc lengths (in degrees) of detected artifacts with respect to the "L" on the section were determined and documented for applicable techniques (+Point probe and Ghent probes). The axial/vertical part of the "L" on the tube section represents the laboratory point zero degree reference azimuthal orientation. The circumferential/horizontal part of the "L" points toward 90 degrees. Table 3-2 summarizes the results of all evaluations performed at Waltz Mill.

3.3 Laboratory Bobbin Probe Data Acquisition and Analysis

Refer to Reference 13 for applicable acquisition and analysis setup parameters that were used for this technique. This Examination Technique Specification Sheet (ETSS) (DMW-02-14) has a test speed of 24 inches/sec. at a sampling rate of 1632 samples/sec. This equates to over twice the required amount of sampling points per inch of tube (~68 samples/inch) (Reference 13). The tester configuration file used was DMW-BOBBIN-12.CFG (Reference 17). As stated in the ETSS, the American Society of Mechanical Engineers (ASME) standard (S/N: ADVB-047-97) was used for this technique. A 0.720 LLMC type bobbin probe was used for this technique and has the serial number (S/N): 646589. Per Reference 13, the voltage settings for the 400 kHz and P1 differential channels were 3.78 and 2.45 volts, respectively, on the 4X20% flat bottom holes (FBHs).

Figure 3-1 through Figure 3-6 illustrate the laboratory bobbin responses for the six sections. Results for the evaluations of this technique are tabulated in Table 3-2. Section R19C38-3B

(02H) has a bobbin voltage response larger than what was reported prior to pulling the tube; a factor of 3 to 4 times increase in the pre-pull bobbin voltage is not unexpected for an axial indication in a pulled tube. The three TSP locations 02H, 03H and 04H (for sections 3B, 5B and 6B, respectively) of R24C41 have a dent response at the area of interest with P1 channel voltages of 13.87, 10.81 and 10.92, respectively. No detectable degradation (NDD) can be observed at these three locations of interest due to the large over-riding dent responses. These dent-like responses are judged as being a result of the tube pull process. Section 2.3 discussed anomalies in the diameter profile for the 02H TSP of R24C41 (shown in Figure 2-18) that appeared to be denting. The two TSH locations where judged to be NDD.

3.4 Three Coil +Point Probe Data Acquisition and Analysis

Refer to Reference 14 for applicable acquisition and analysis setup parameters that were used for this technique. Per this ETSS (DMW-05-14), the tester configuration file used was DMW-3COIL+PT-12.CFG (Reference 17). The electrode discharge machining (EDM) standard that was used for this technique was S/N: EP5-054-98. The motor unit and probe head used for this technique have S/Ns: 467571 and 455341, respectively.

Figure 3-7 through Figure 3-14 illustrate the laboratory three (3) coil 300 kHz +Point probe responses for the six sections. Results for the evaluations of this technique are tabulated in Table 3-2. The laboratory +Point probe responses are relatively consistent with the data collected prior to the tube pulls. The voltages are consistent as to what was reported in the field.

Section R19C38-3B (02H) was evaluated as having SAIs located at the top and bottom locations of the support plate. Section R24C41-6B (04H) was reported in the field ECT as having two single axial indications (SAI) in the same axial location (Table 3-2), which is actually the definition of a multiple axial indication (MAI). Each ligament of the MAI was evaluated with similar amplitudes to what was reported in the field (see Figure 3-13 and Figure 3-14). The dent-like response observed during the laboratory bobbin testing of R24C41 did not affect detectability for this +Point technique in the laboratory. The results of the remaining four sections were consistent with what was reported in the field prior to pulling the tubes (NDD).

Figure 3-7 and Figure 3-10 also show three long parallel axial artifacts below the top of the tubesheet. These are TIG welds used in the tube pull operation to relax the tube-tubesheet joint.

3.5 Ghent Acquisition and Analysis

Refer to Reference 15 for applicable acquisition and analysis setup parameters that were used for this technique. Per this ETSS (DMW-12-14), the tester configuration file used was DMW-RG3-4-12.CFG (Reference 17). The EDM standard that was used for this technique was S/N: EP5-054-98. The motor unit and probe head used for this technique have S/Ns: 467571 and 583268, respectively.

Figure 3-15 through Figure 3-23 illustrate the laboratory 300 kHz axial-sensitive Ghent responses for the six sections. Results for the evaluations of this technique are tabulated in Table 3-2. These voltages are representative to the +Point probe voltages in the laboratory and as to what was reported in the field.

Section R19C38-3B (02H) was evaluated as having SAIs located at the top and bottom locations of the support plate. The Ghent response for section R24C41-6B (04H) revealed three ligaments for the MAI, with the additional ligament (3) being small in voltage (0.10 volts). The dent-like responses observed during the laboratory bobbin testing of R24C41 did not affect detectability for this Ghent probe technique in the laboratory. The results of the remaining four sections were consistent with what was reported in the field prior to pulling the tubes (NDD).

Figure 3-15 and Figure 3-18 also show three long parallel axial artifacts below the top of the tubesheet. These are TIG welds used in the tube pull operation to relax the tube-tubesheet joint.

3.6 Review of Field Data Prior to the Tube Pull Process

A re-evaluation of the field data collected prior to the tube pulling process was performed. Results of the re-evaluation are consistent to the results reported in the field, except with the interpretation or classification of R24C41 at 04H. The field evaluation reported two separate SAIs for this intersection with both located at the same axial location of the tube. This condition is interpreted as MAIs in the re-evaluation in the laboratory. Results of this field data review are tabulated in Table 3-2. Figure 3-24 through Figure 3-29 illustrate the re-evaluation responses for the bobbin technique and Figure 3-30 through Figure 3-36 for the +Point probe technique.

3.7 ECT Conclusions

A comparison of pre-pull and post-pull rotating probe voltages shows little change from the tube-pull process. In the case of R19C38-3B (02H), the bobbin voltage increased by a factor of 3.5 most likely from the pulling operation, which is typical of Westinghouse experience for pulled tubes with small voltage axial indications and does not indicate a significant alteration in the pre-pull condition from the pulling operation. The pulling operation likely had little effect on the crack-like indications. The post-pull bobbin examination performed in the laboratory revealed significant dent-like indications at all three TSP locations of R24C41 that were not reportable prior to the tube pull. These dent-like responses of tube R24C41 masked laboratory bobbin detectability of the DSIs that were reported in the field data prior to the tube pull.

The field indication identified by bobbin coil at R24C41-3B (02H), which was not confirmed by field +Point probe, was also found to be NDD by both laboratory rotating probes as well.

The laboratory eddy current testing did not identify any false-positive field indications.

Table 3-1: ECT Samples

Tube	Section	Region of Interest	Location of Center of Area of Interest	Location of "L" Indicator
R19C38	1B	TTS (TSH)	Bottom 1B to TSH = 8.4"	Above TSH
R19C38	3B	02H	Bottom 3B to 02H = 6.0"	Above 02H
R24C41	1B	TTS (TSH)	Bottom 1B to TSH = 9.7"	Below TSH
R24C41	3B	02H	Bottom 3B to 02H = 6.0"	Above 02H
R24C41	5B	03H	Bottom 5B to 03H = 4.5"	Above 03H
R24C41	6B	04H	Bottom 6B to 04H = 6.0"	Above 04H

TSH – Same as TTS. Top of Hot Leg Tubesheet

Table 3-2: Summary of Field and Laboratory Eddy Current Inspection Results

Tube Section - Region	Pre-Pull Field Eddy Current		Pre-Pull Field Data Review		Laboratory Eddy Current		
	Bobbin Coil IND / Volts*	+Point IND / Volts*	Bobbin Coil IND/Volts*	+Point IND / Volts*	Bobbin Coil IND / Volts*	+Point IND / Volts* / Azimuth	Ghent IND / Volts* / Azimuth
R19C38 1B – TSH	NDD	NDD	NDD	NDD	NDD	NDD	NDD
R19C38 3B - 02H	DSI / 0.62v	SAI (Top&Bot) SAI(Top) / 0.25v SAI(Bot) / 0.15v	DSI / 2.01v	SAI (Top&Bot) SAI(Top) / 0.17v SAI(Bot) / 0.11v	DSI / 2.15v	SAI (Top&Bot) SAI(Top) / 0.15v / 337° SAI(Bot) / 0.17v / 5°	SAI(Top&Bot) SAI(Top) / 0.28v / 337° SAI(Bot) / 0.34v / 8°
R24C41 1B - TSH	NDD	NDD	NDD	NDD	NDD	NDD	NDD
R24C41 3B - 02H	DSI / 1.19v	NDF	DSI / 1.25v	NDF	DNT / 13.87v	NDD	NDD
R24C41 5B - 03H	NDD	NI	NDD	NI	DNT / 10.81v	NDD	NDD
R24C41 6B - 04H	DSI / 0.47v	SAI (2 Reported) SAI(1) / 0.23v SAI(2) / 0.09v	DSI / 0.56v	MAI (2 Ligaments) MAI(Lig1) / 0.16v MAI(Lig2) / 0.11v	DNT / 10.92v	MAI (2 Ligaments) MAI(Lig1) / 0.21v / 333° MAI(Lig2) / 0.09v / 92°	MAI (3 Ligaments) MAI(Lig1) / 0.57v / 336° MAI(Lig2) / 0.15v / 88° MAI(Lig3) / 0.10v / 29°

*Bobbin voltages are from the P1 channel; +Point and Ghent are from the 300 kHz axial channel

NDF - No Degradation Found
NDD - No Detectable Degradation
SAI- Signal Axial Indication
DNT - Dented Location
NI - Not Inspected
NA - Not applicable
MAI - Multiple Axial Indication
Lig - Ligament of MAI
TSH – Top of the Hot Leg Tubesheet (Same as TTS)
DSI – Distorted Support Indication
Azimuth – Circumferential degrees from the axial part of the "L" starting in the direction of the horizontal part of the "L"

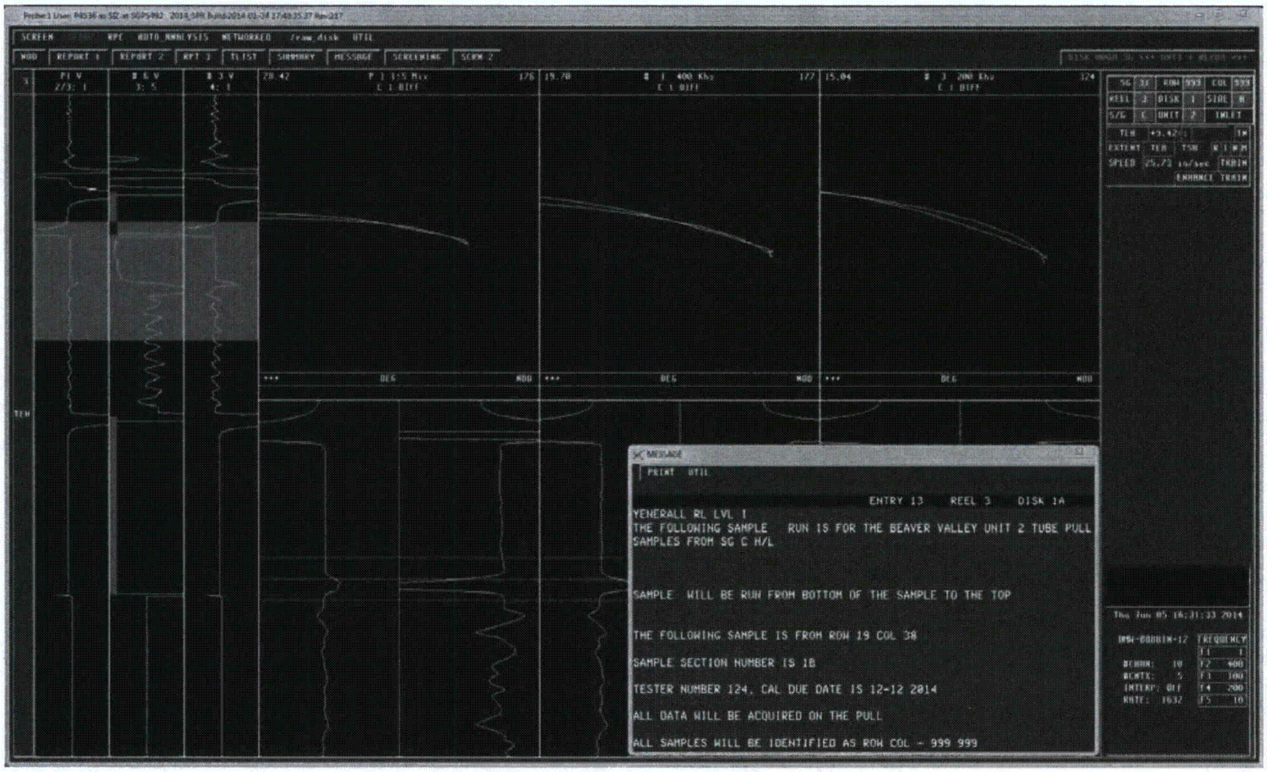


Figure 3-1: Laboratory Bobbin – R19C38-1B TSH – NDD

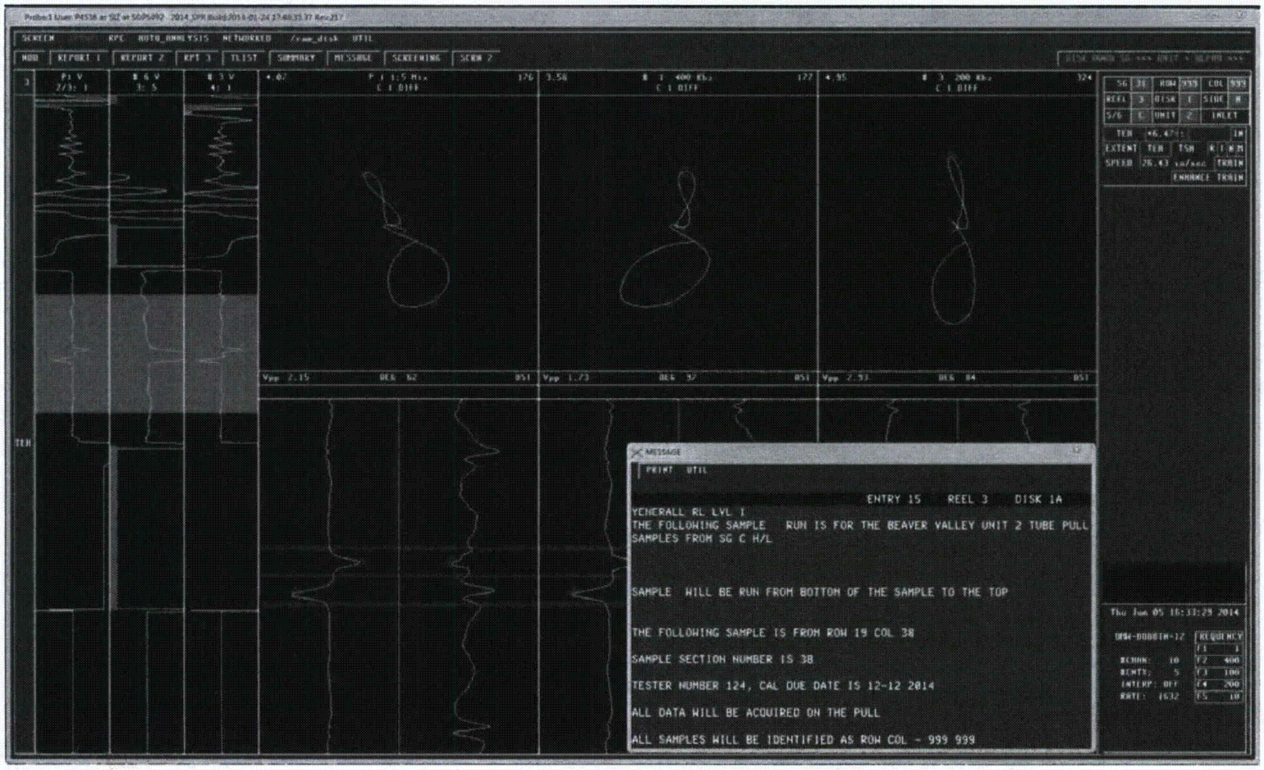


Figure 3-2: Laboratory Bobbin – R19C38-3B (02H) - DSI

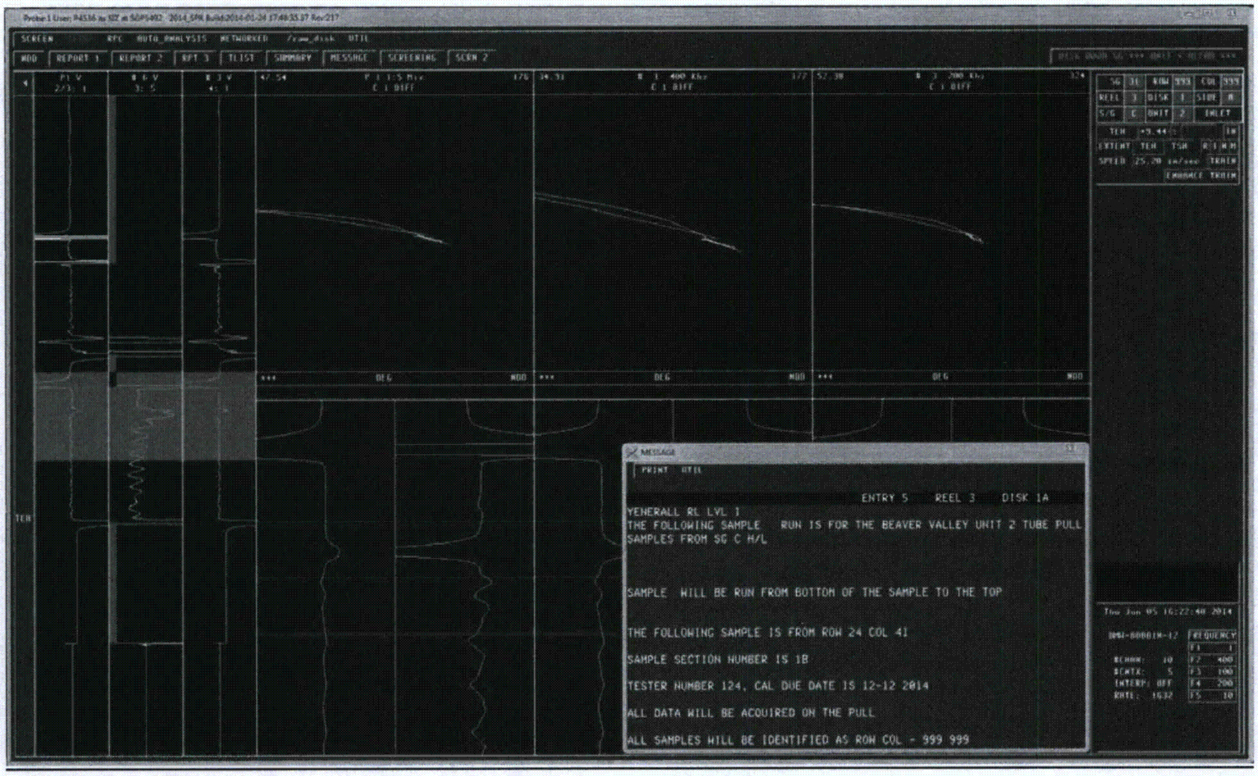


Figure 3-3: Laboratory Bobbin – R24C41-1B (TSH) - NDD

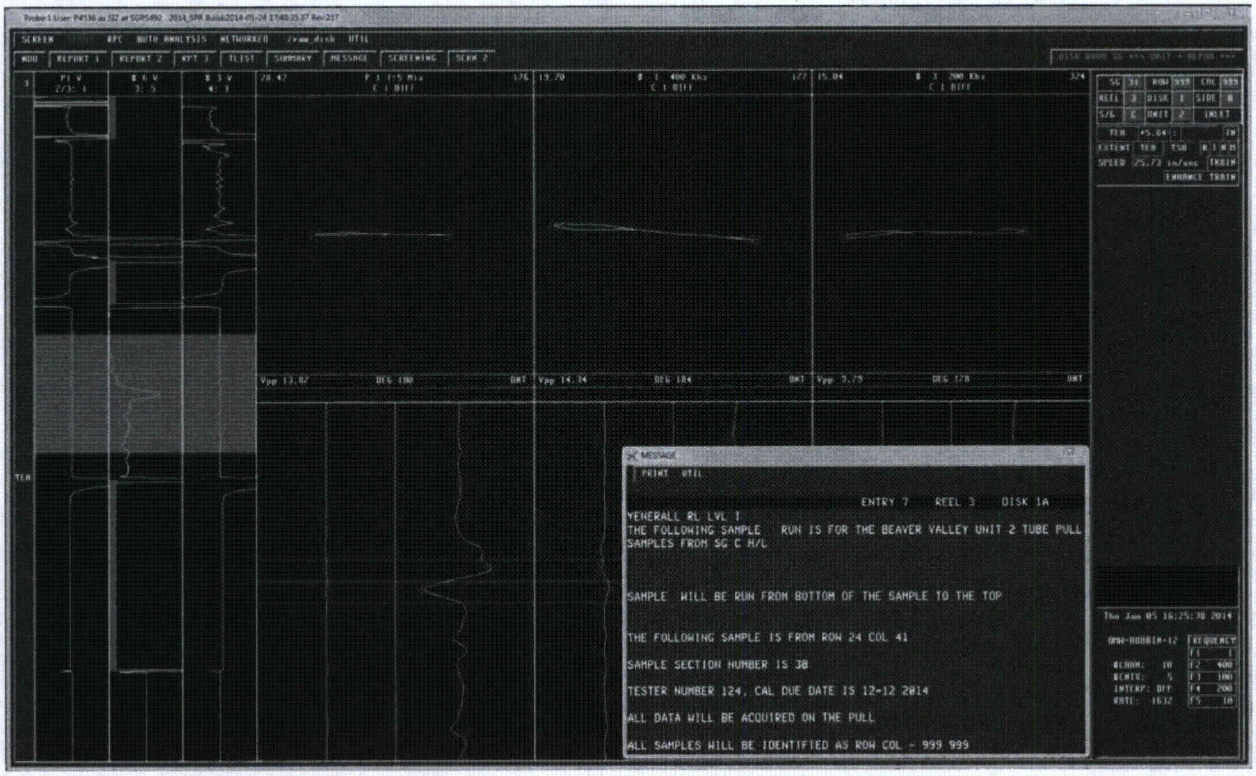


Figure 3-4: Laboratory Bobbin – R24C41-3B (02H) - DNT

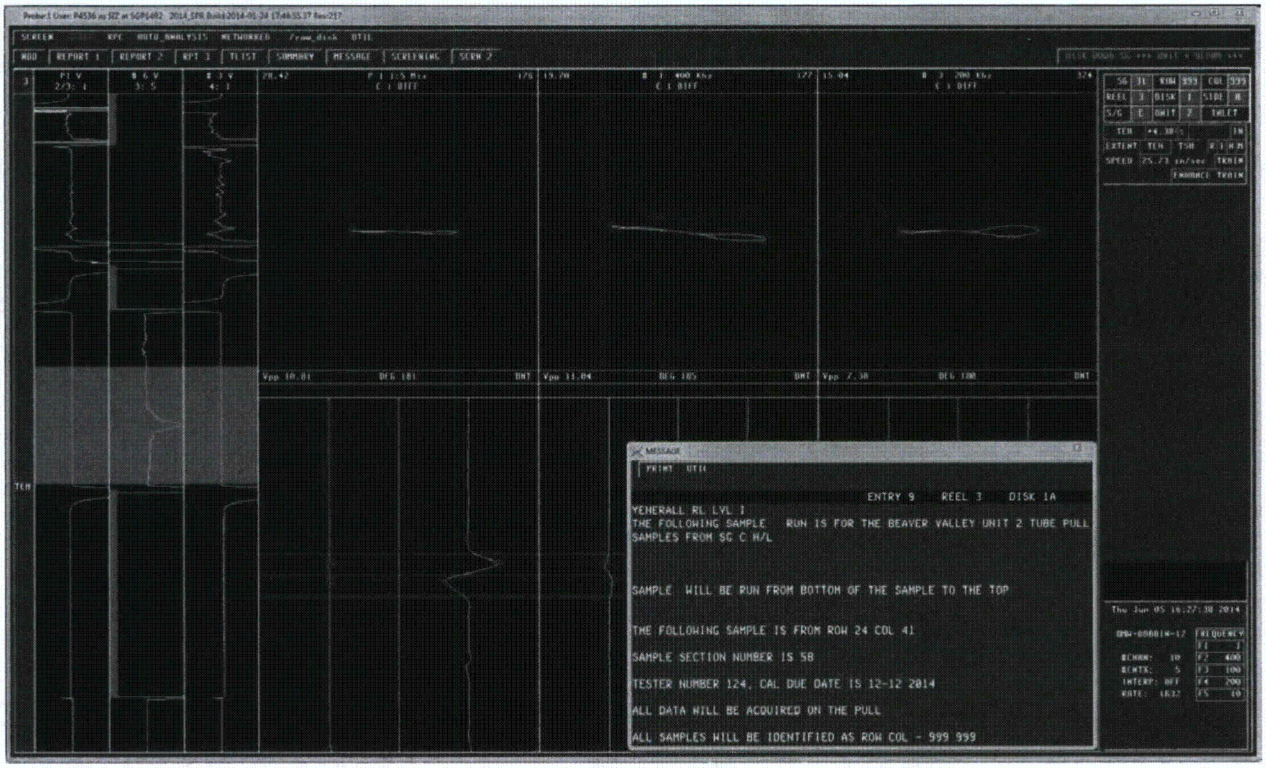


Figure 3-5: Laboratory Bobbin – R24C41-5B (03H) - DNT

Figure 3-6: Laboratory Bobbin – R24C41-6B (04H) - DNT

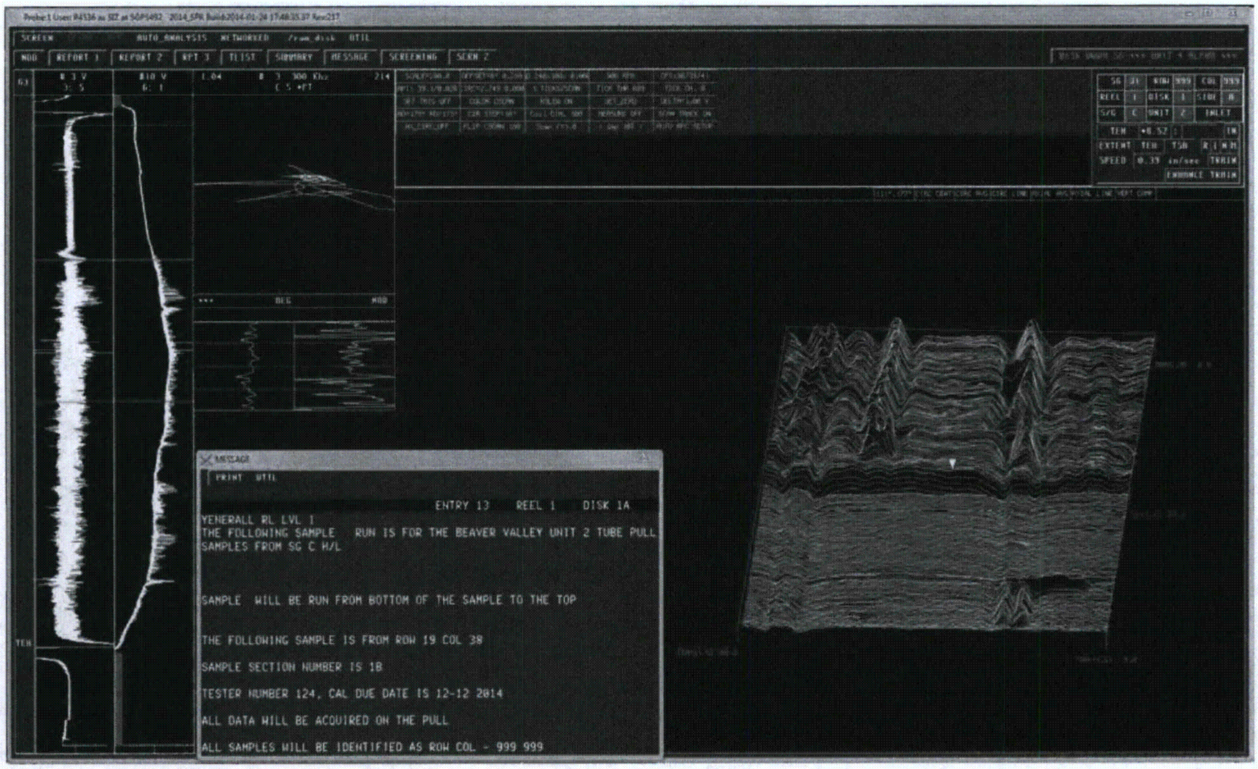


Figure 3-7: Laboratory +Point Probe – R19C38-1B TSH - NDD

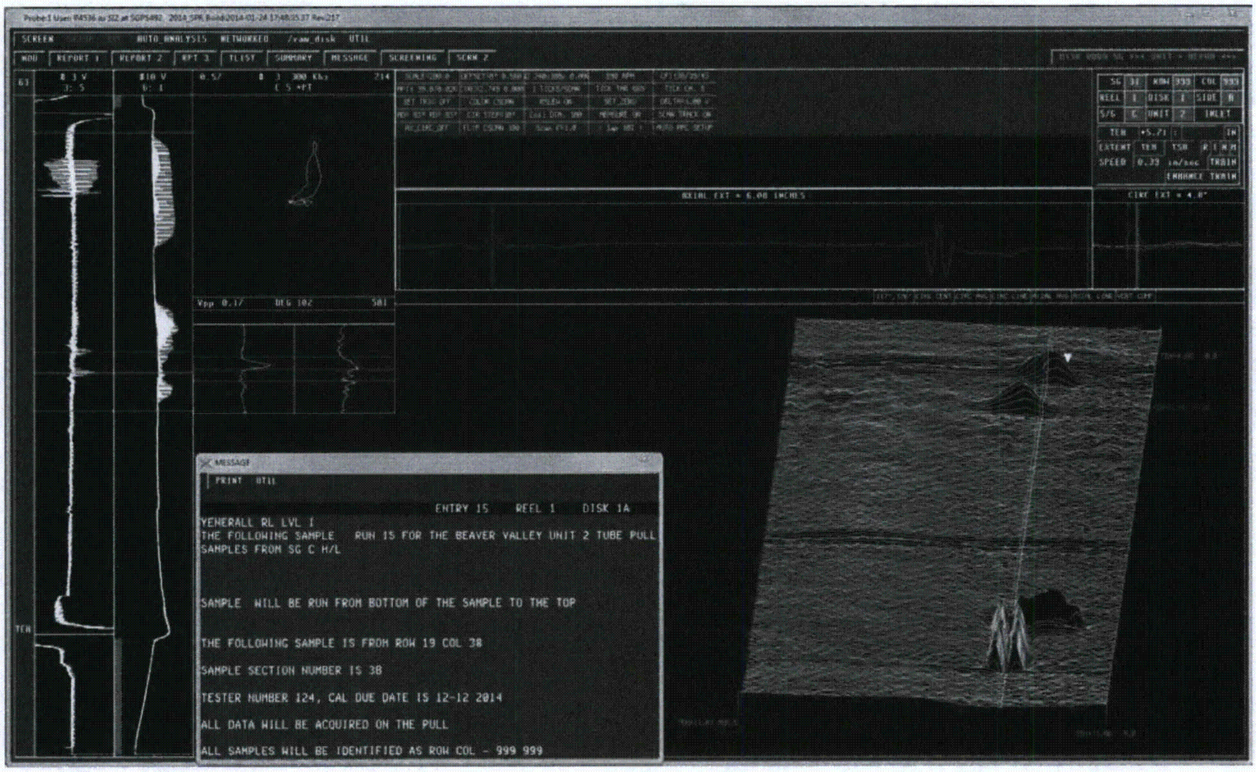


Figure 3-8: Laboratory +Point Probe – R19C38-3B (02H) – Bottom – SAI

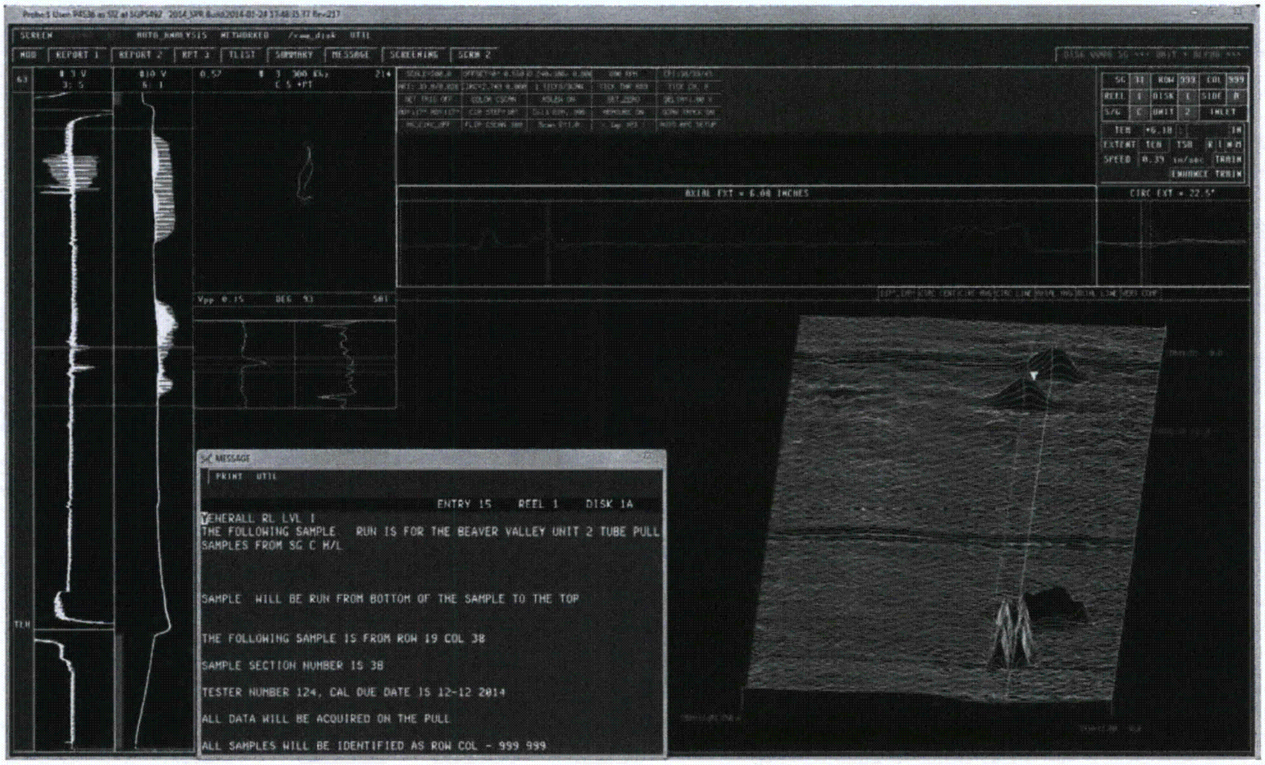


Figure 3-9: Laboratory +Point Probe – R19C38-3B (02H) – Top – SAI

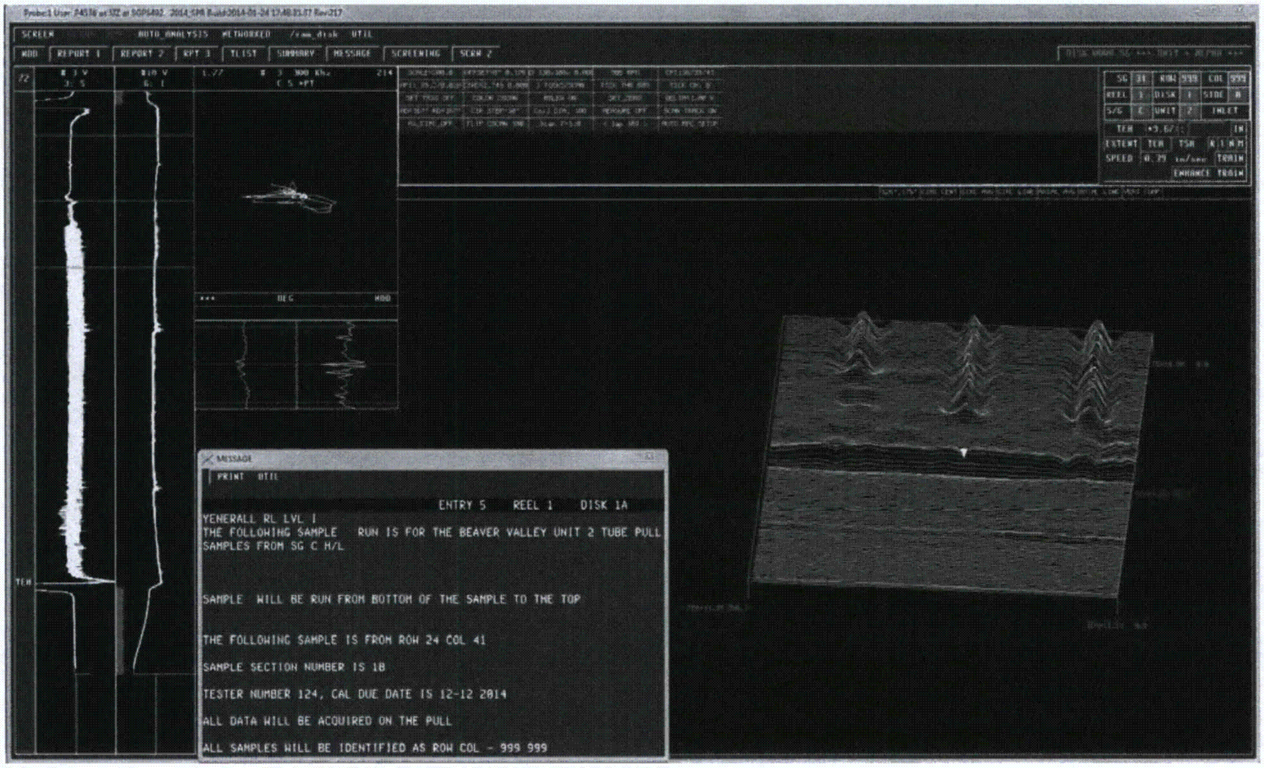


Figure 3-10: Laboratory +Point Probe – R24C41-1B TSH - NDD

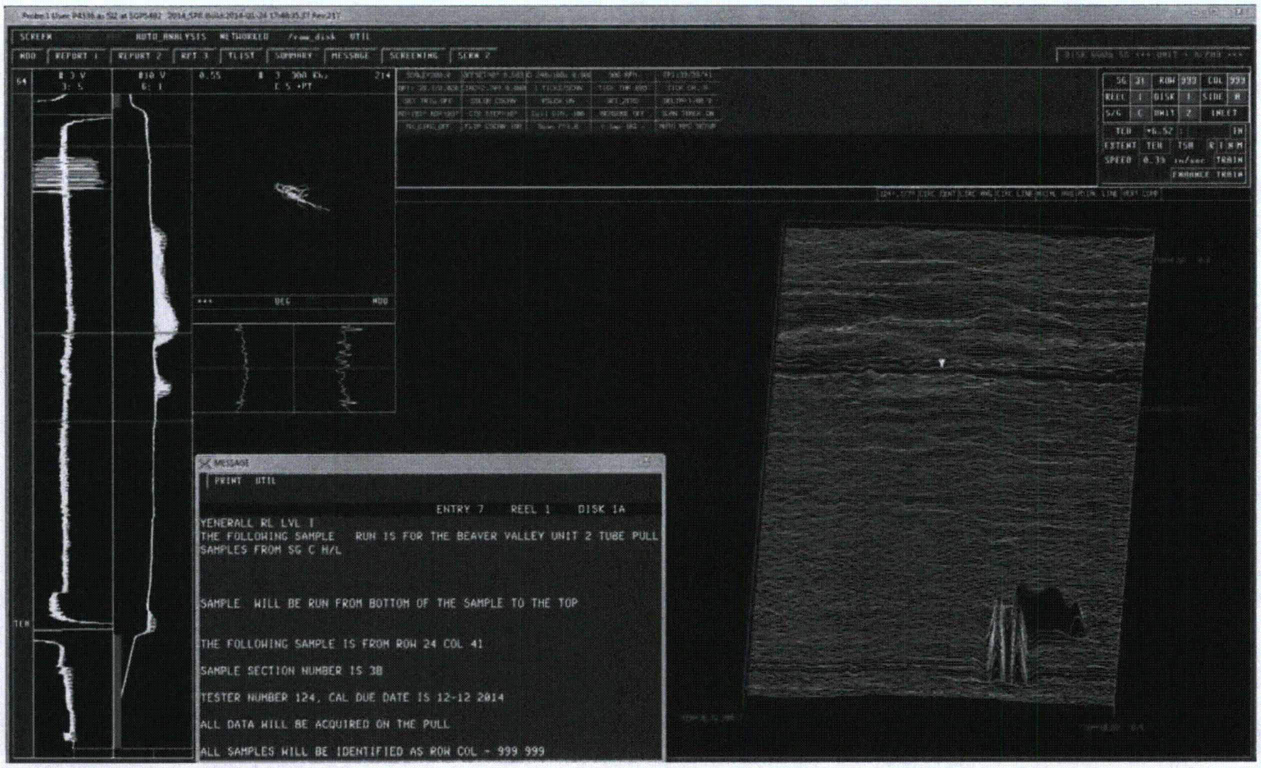


Figure 3-11: Laboratory +Point Probe – R24C41-3B (02H) - NDD

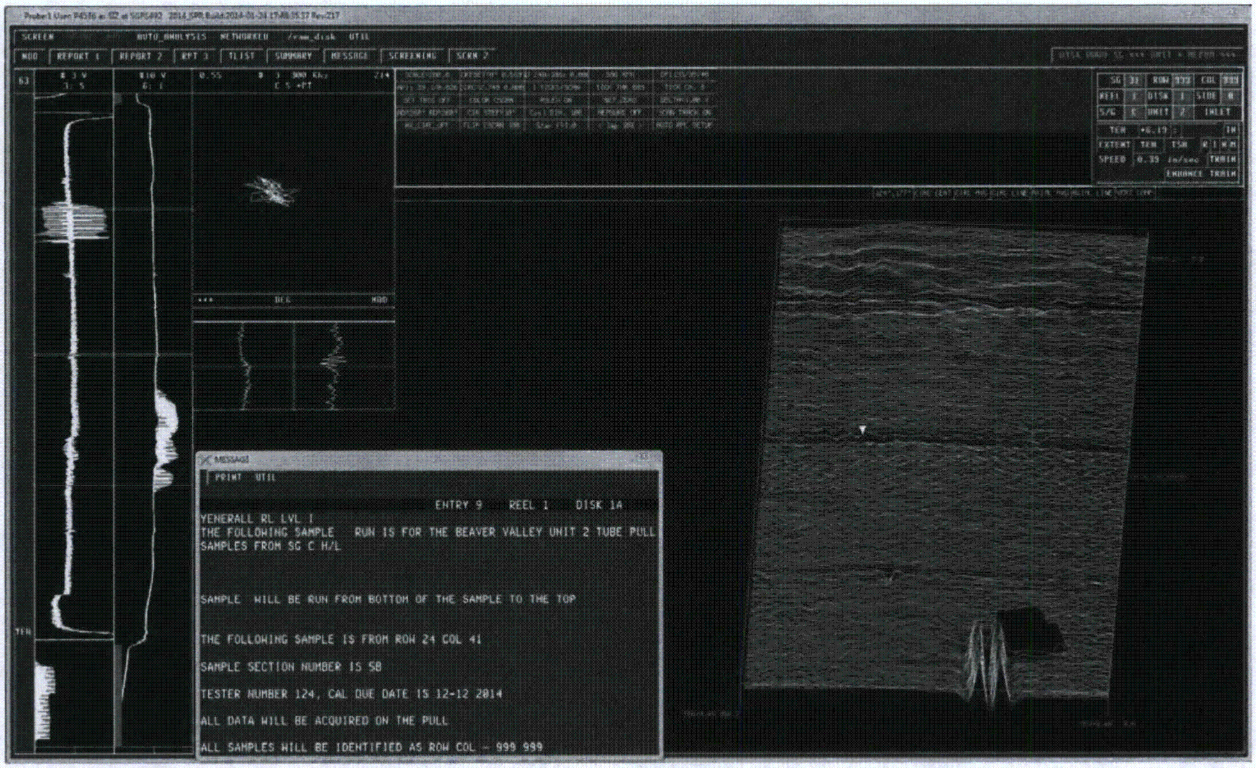


Figure 3-12: Laboratory +Point Probe – R24C41-5B (03H) – NDD

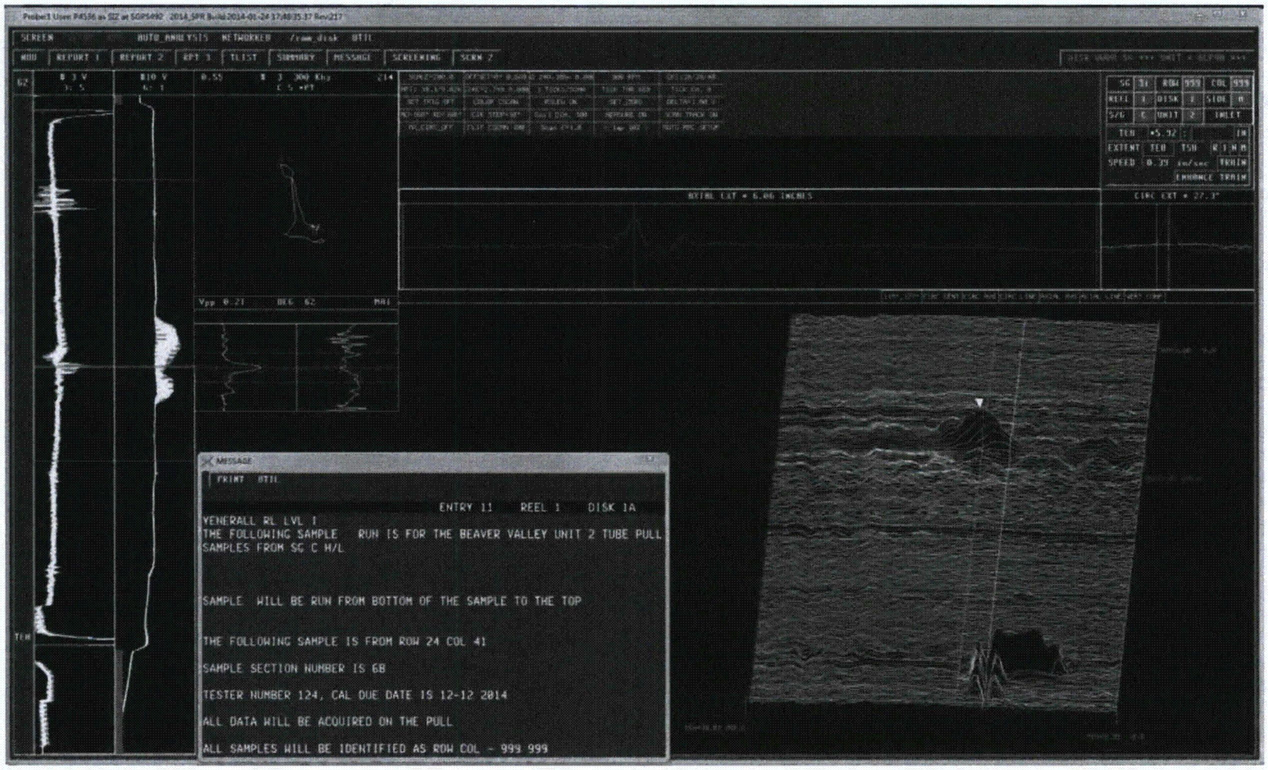


Figure 3-13: Laboratory +Point Probe – R24C41-6B (04H) - Ligament # 1 - MAI

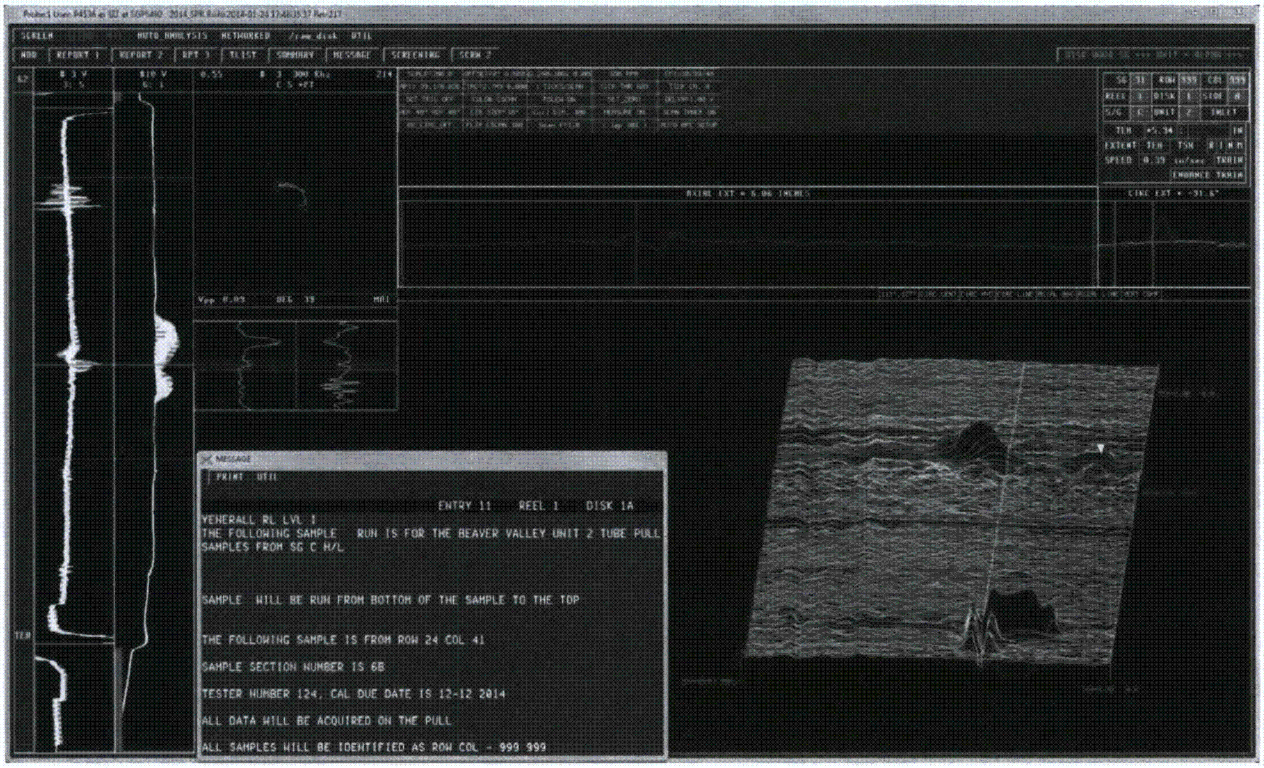


Figure 3-14: Laboratory +Point Probe – R24C41-6B (04H) - Ligament # 2 – MAI

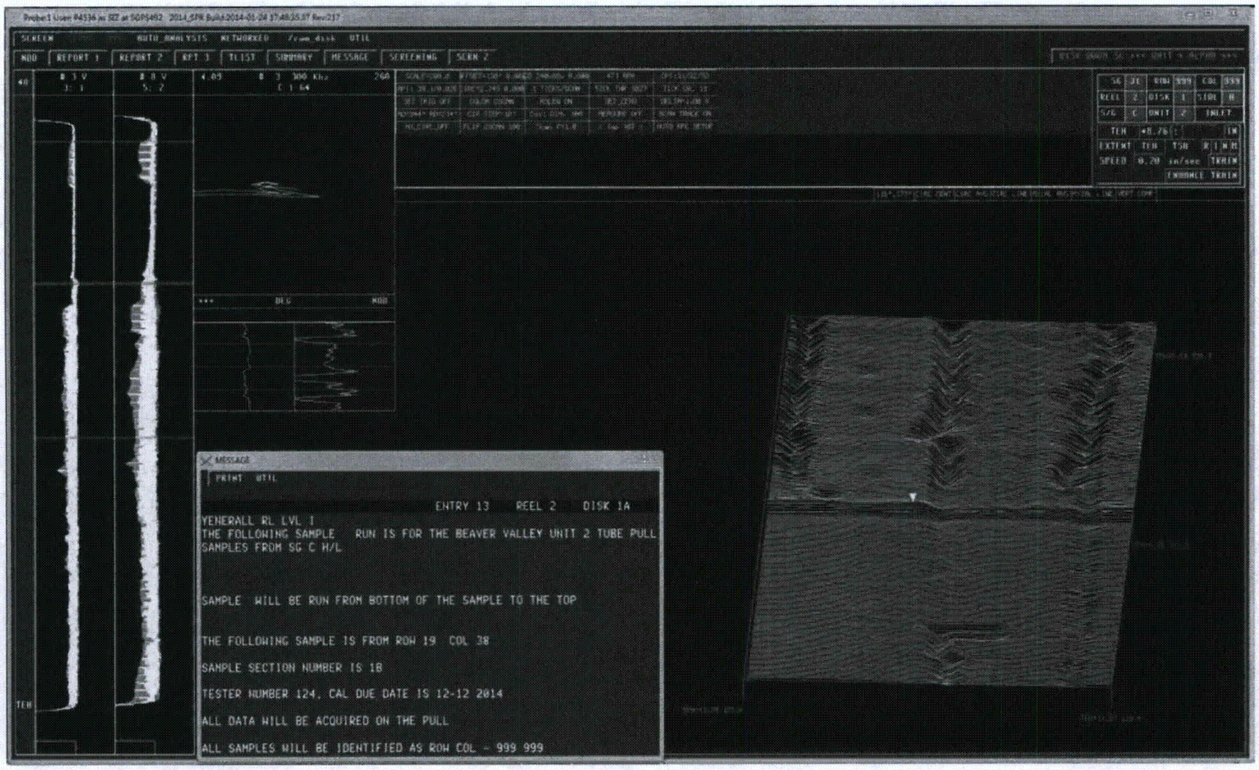


Figure 3-15: Laboratory Ghent Probe – R19C38-1B TSH – NDD

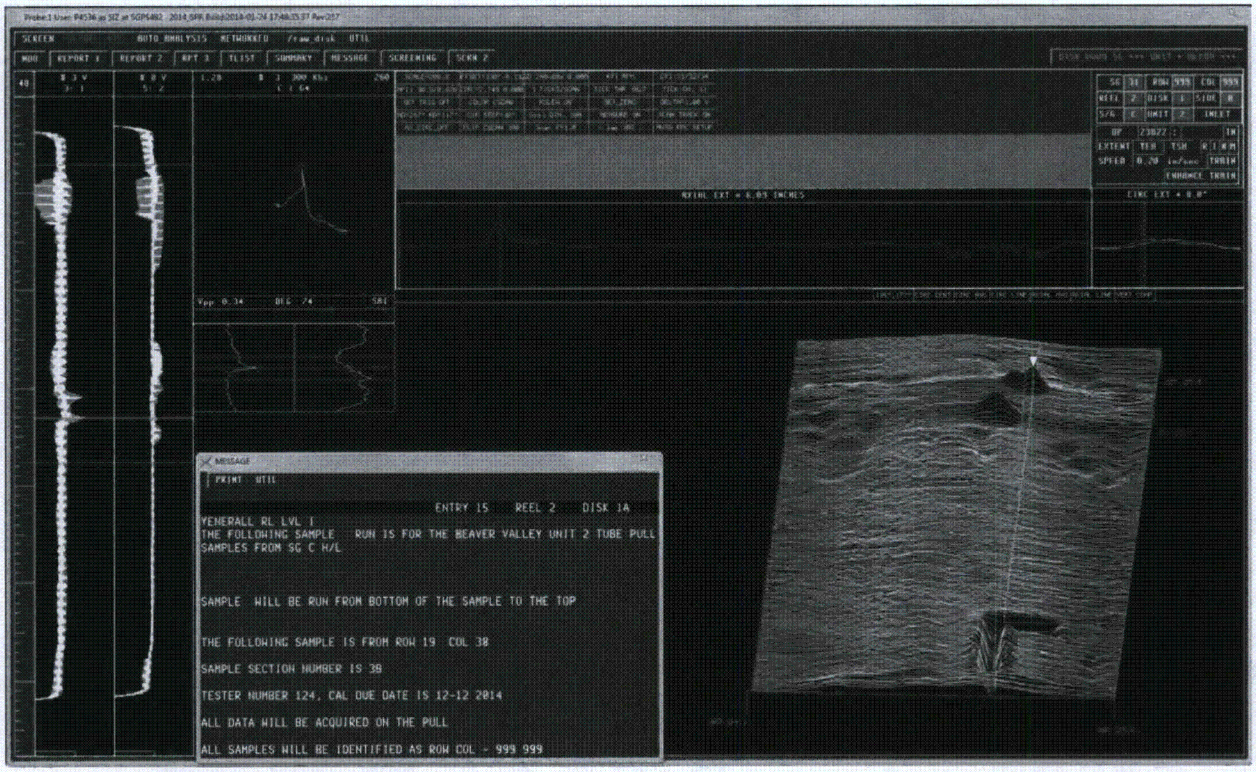


Figure 3-16: Laboratory Ghent Probe – R19C38-3B (02H) - Bottom – SAI

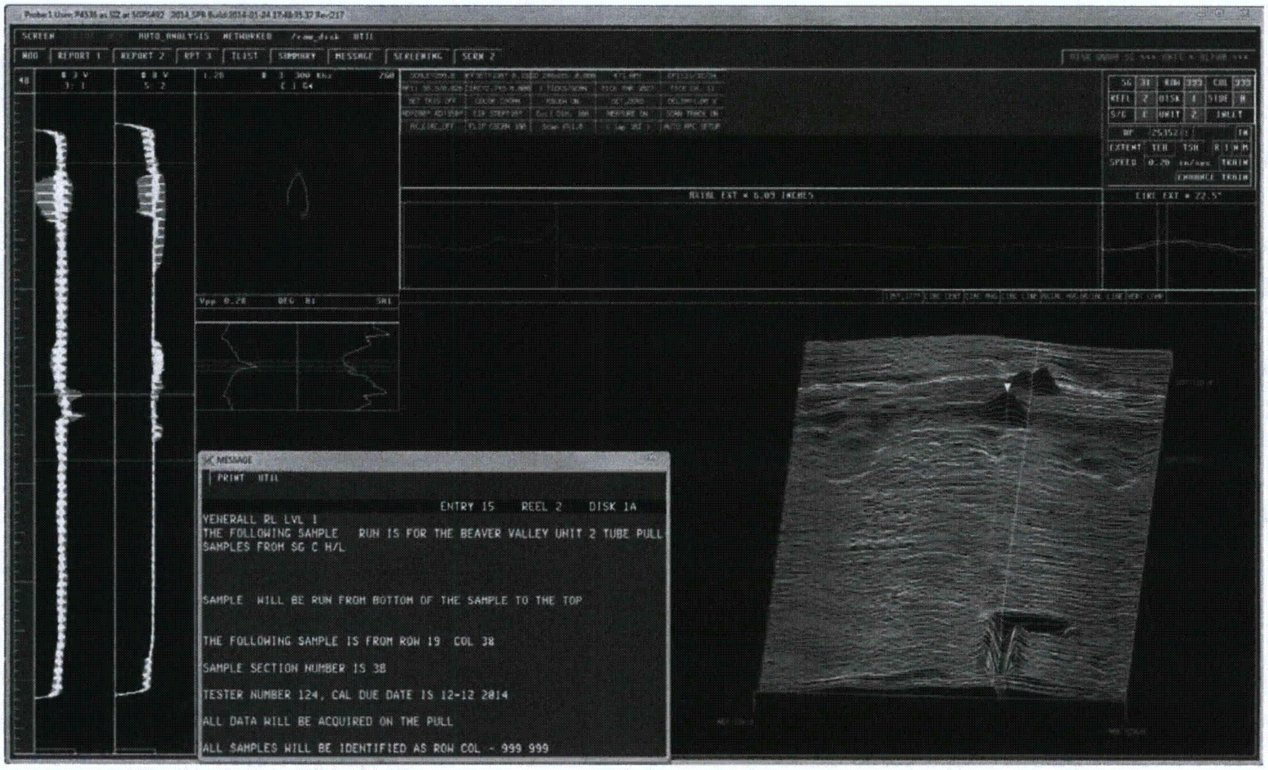


Figure 3-17: Laboratory Ghent Probe – R19C38-3B (02H) - Top – SAI

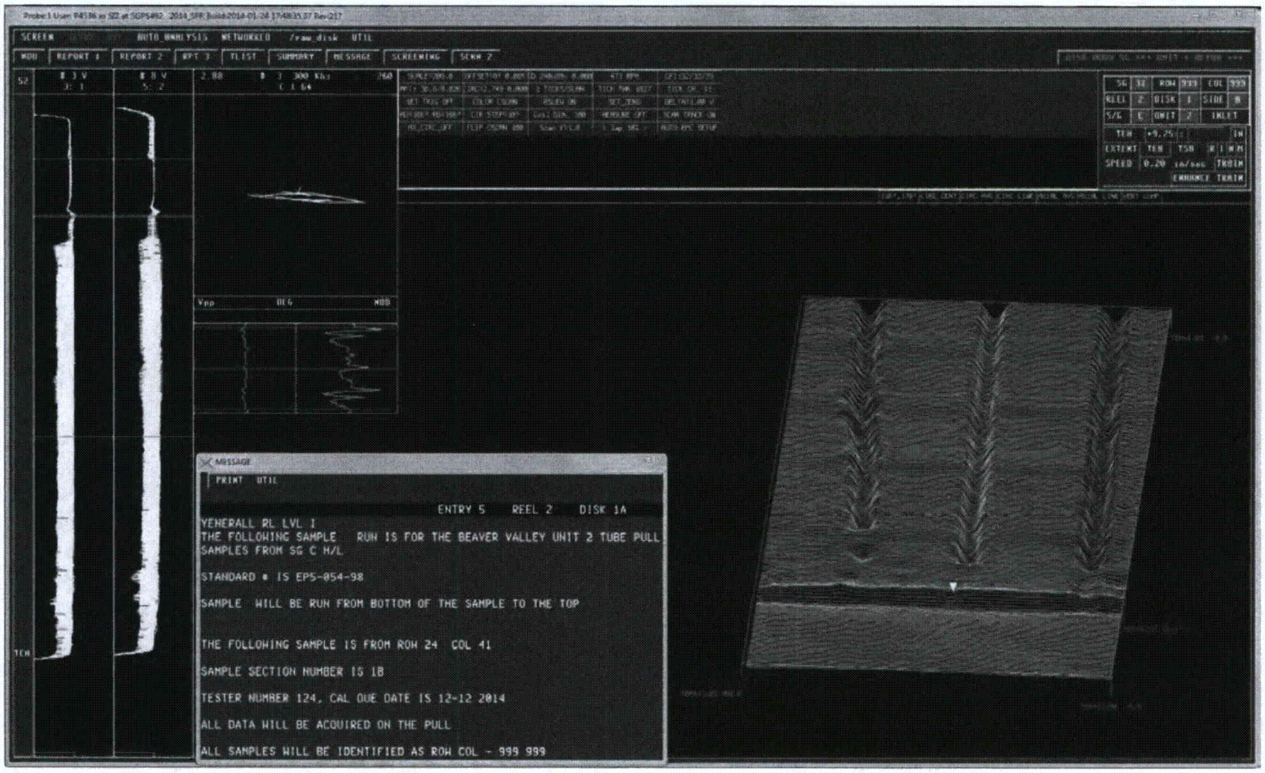


Figure 3-18: Laboratory Ghent Probe – R24C41-1B TSH – NDD

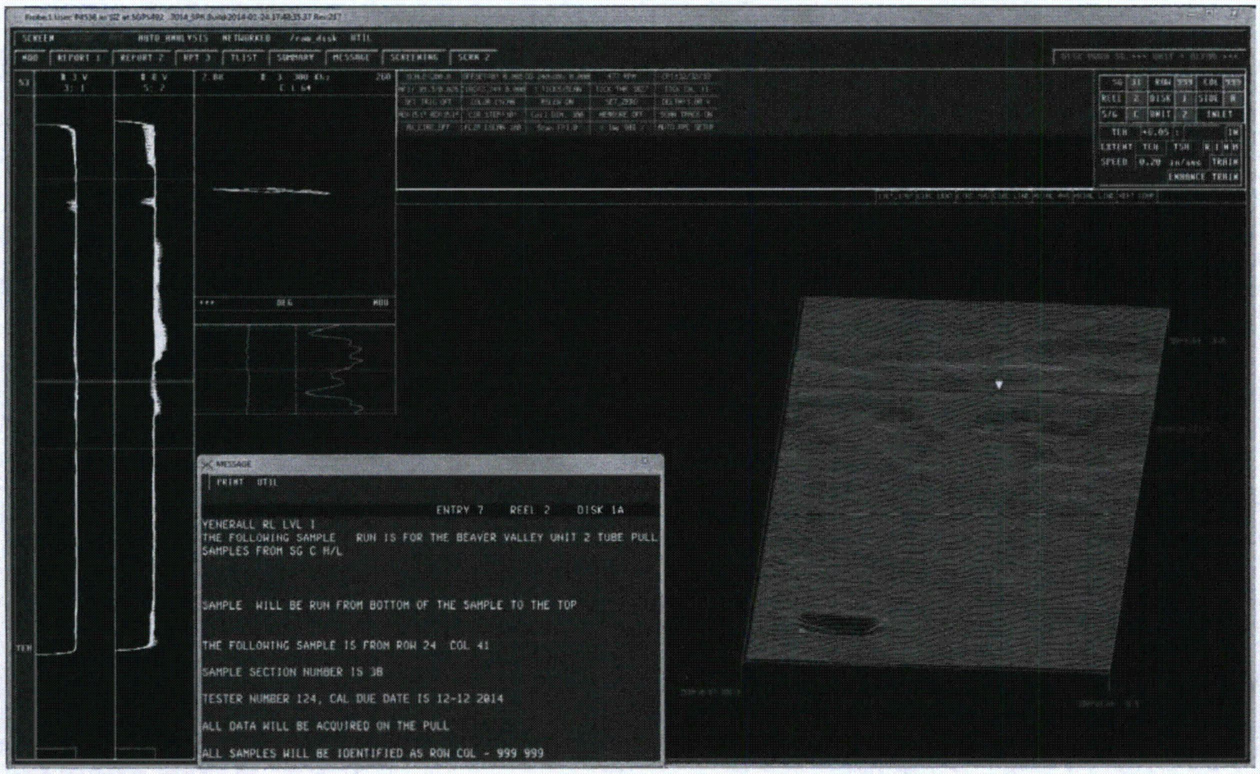


Figure 3-19: Laboratory Ghent Probe – R24C41-3B (02H) – NDD

Figure 3-20: Laboratory Ghent Probe – R24C41-5B (03H) – NDD

Figure 3-21: Laboratory Ghent Probe – R24C41-6B (04H) – Ligament # 1 – MAI

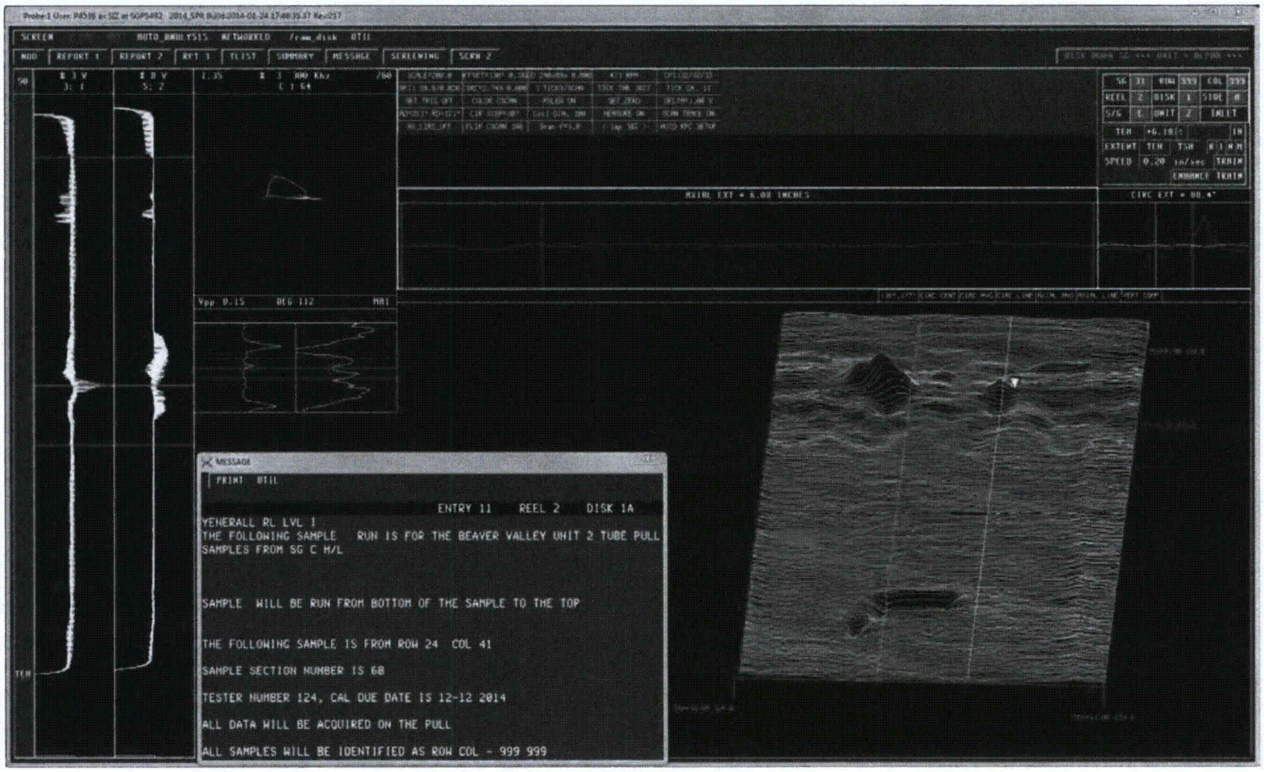


Figure 3-22: Laboratory Ghent Probe – R24C41-6B (04H) – Ligament # 2 – MAI

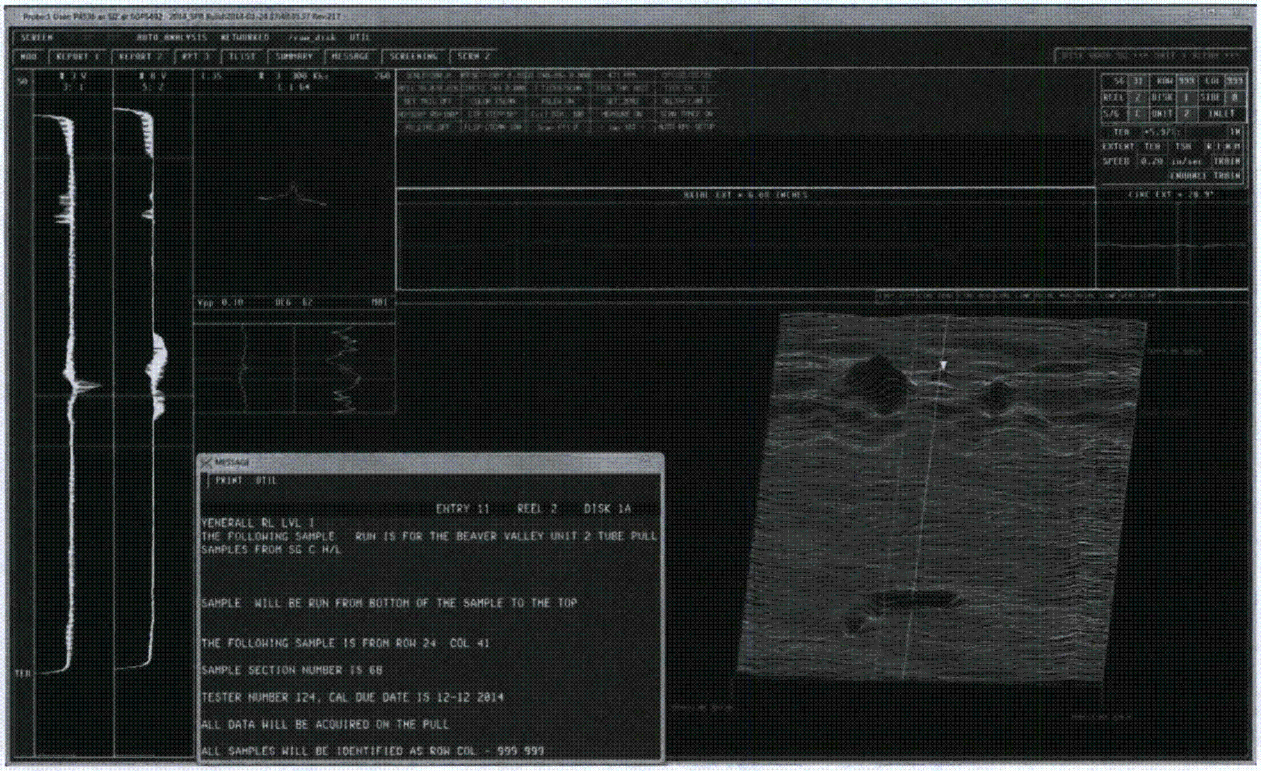


Figure 3-23: Laboratory Ghent Probe – R24C41-6B (04H) – Ligament # 3 – MAI

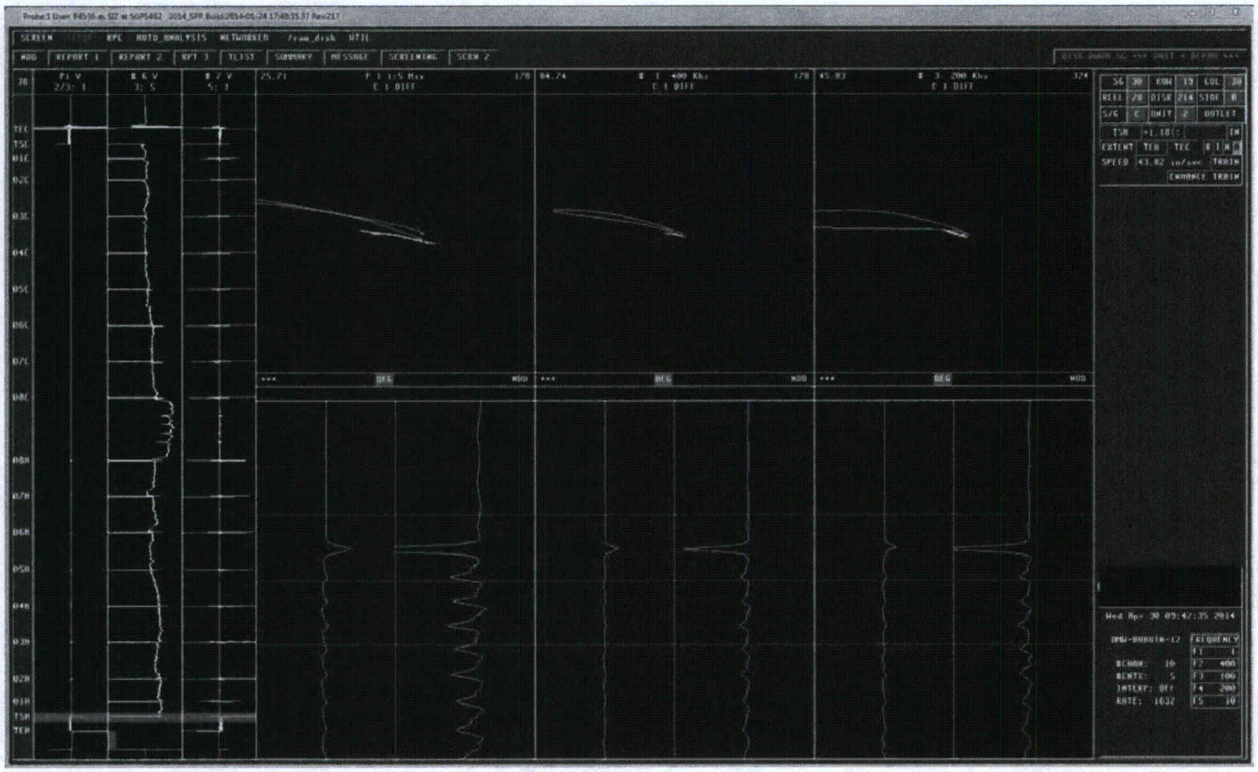


Figure 3-24: In-Generator Bobbin Probe – R19C38-1B TSH - NDD

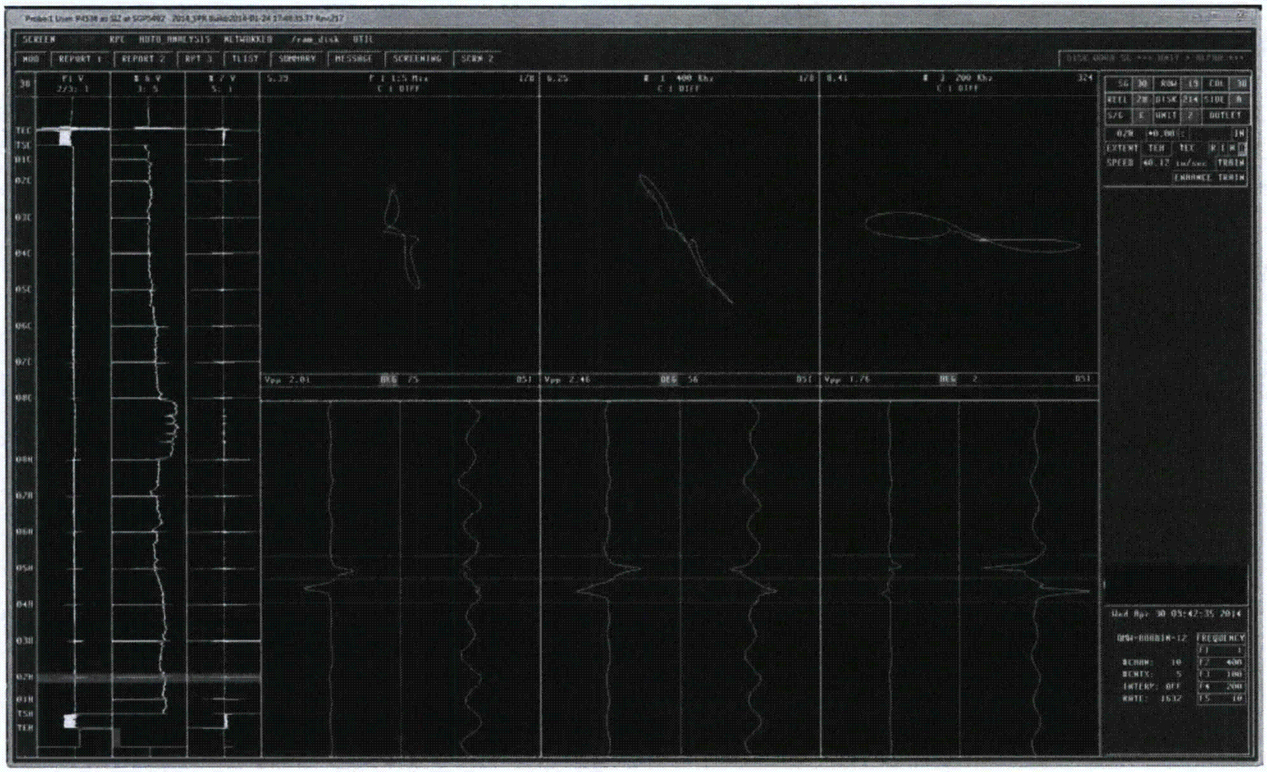


Figure 3-25: In-Generator Bobbin Probe – R19C38-3B (02H) – DSI

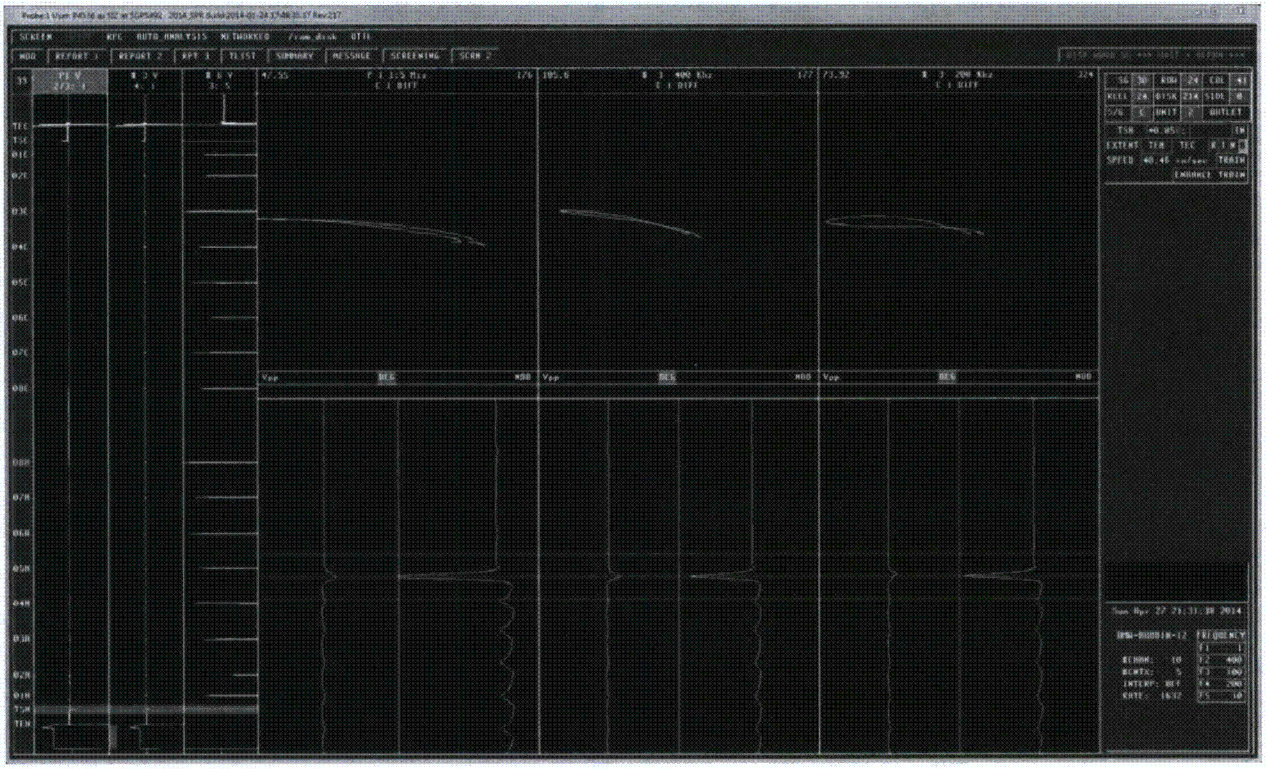


Figure 3-26: In-Generator Bobbin Probe – R24C41-1B TSH - NDD

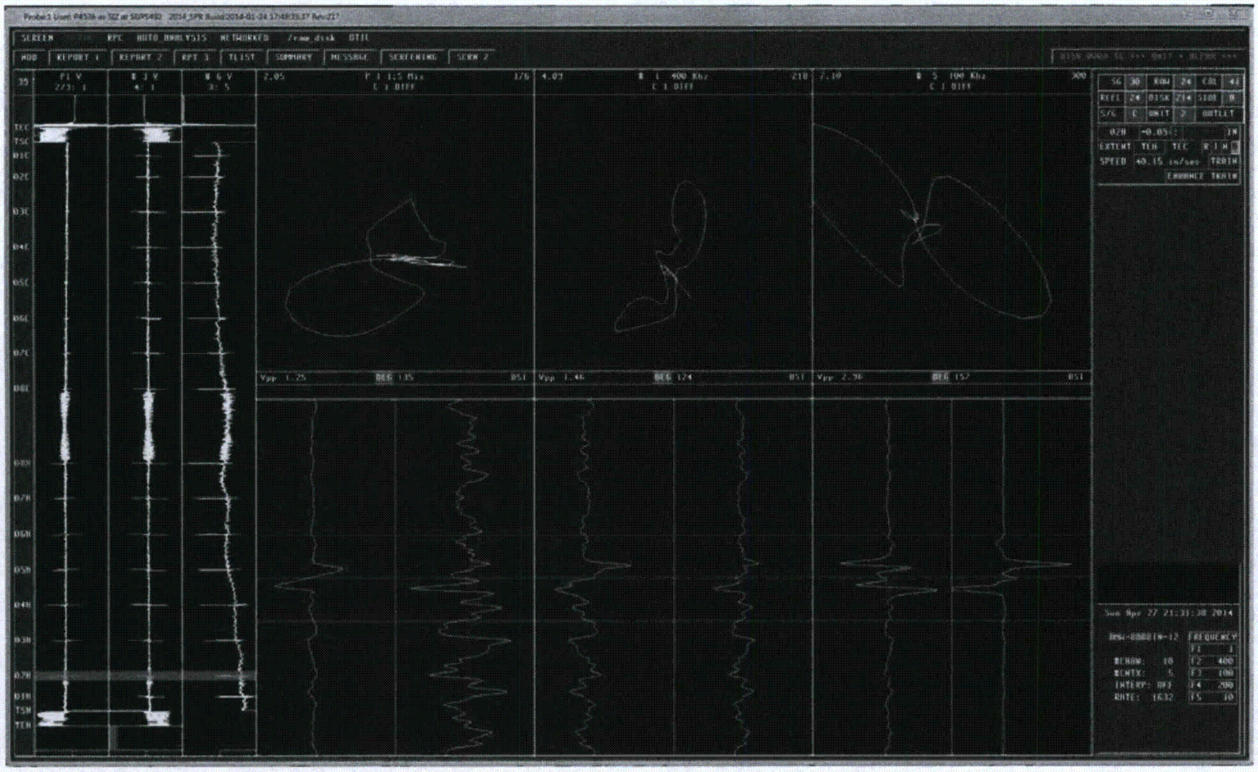


Figure 3-27: In-Generator Bobbin Probe – R24C41-3B (02H) – DSI

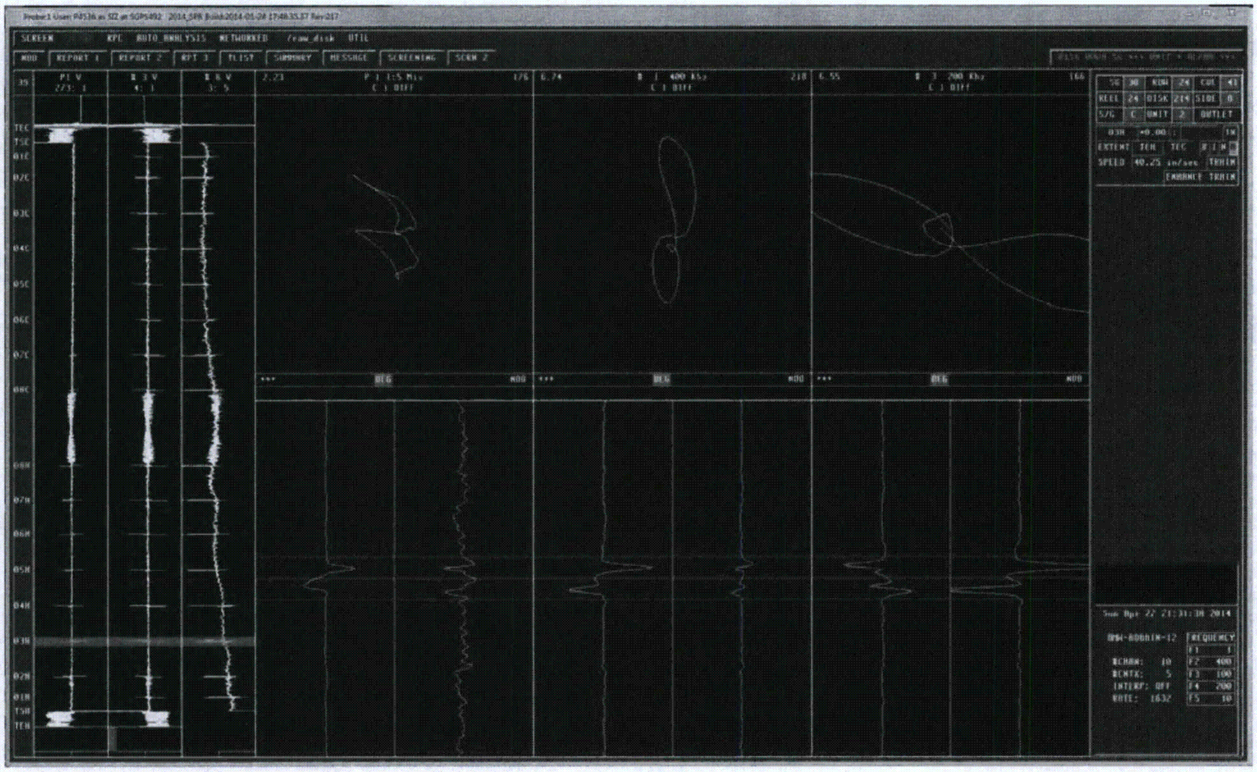


Figure 3-28: In-Generator Bobbin Probe – R24C41-5B (03H) - NDD

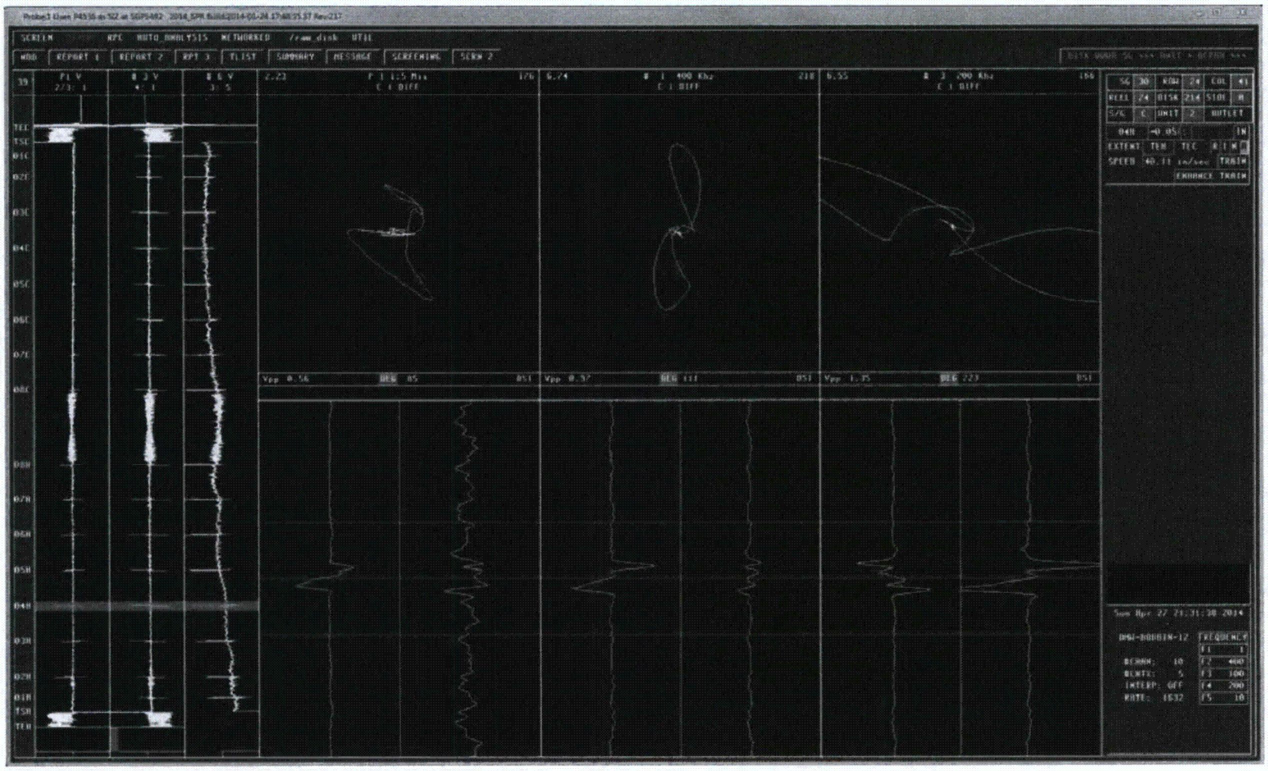


Figure 3-29: In-Generator Bobbin Probe – R24C41-6B (04H) - DSI

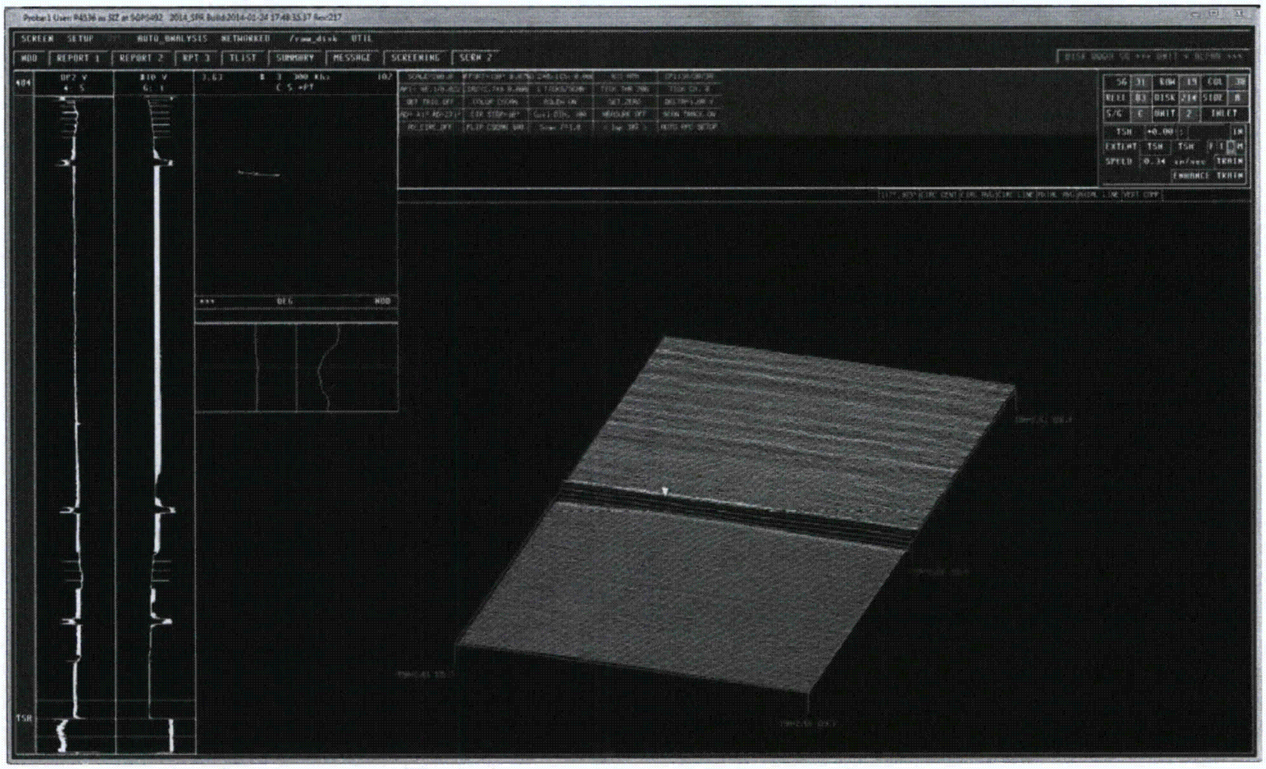


Figure 3-30: In-Generator +Point Probe – R19C38-1B TSH – NDD

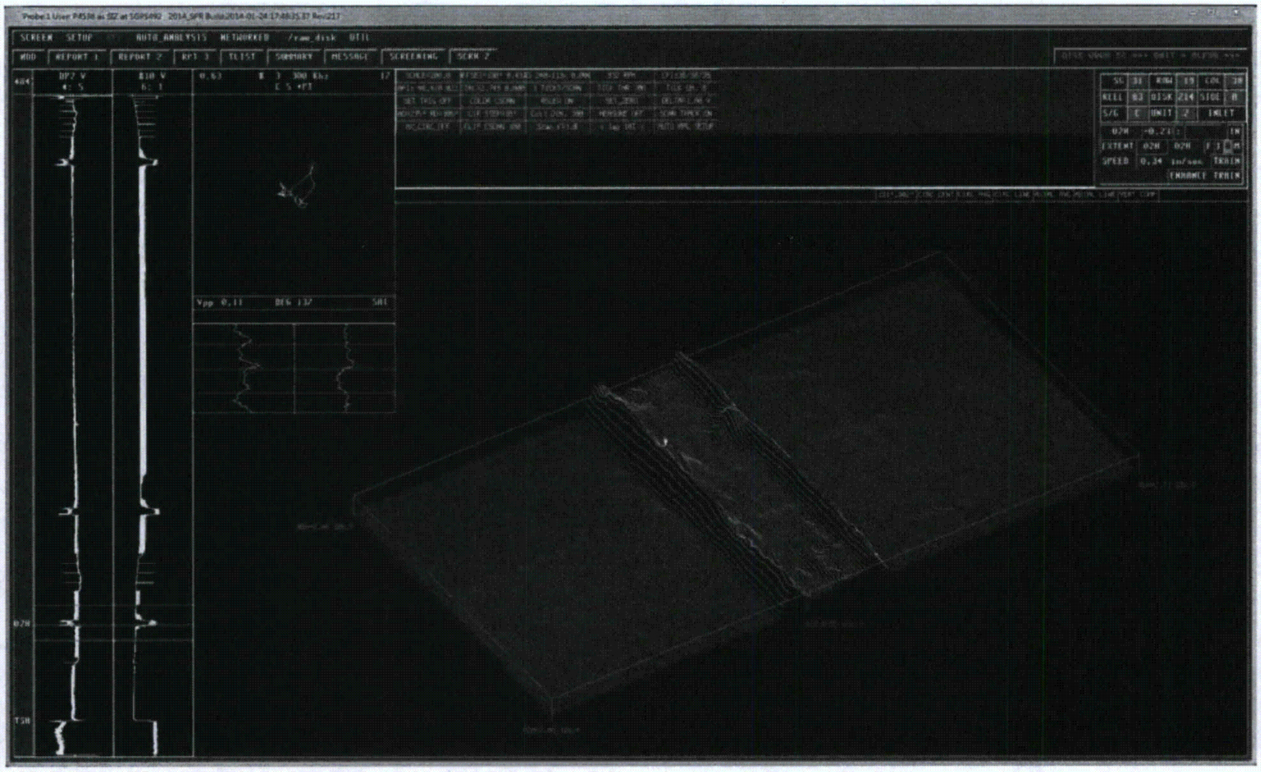


Figure 3-31: In-Generator +Point Probe – R19C38-3B (02H) – Bottom – SAI

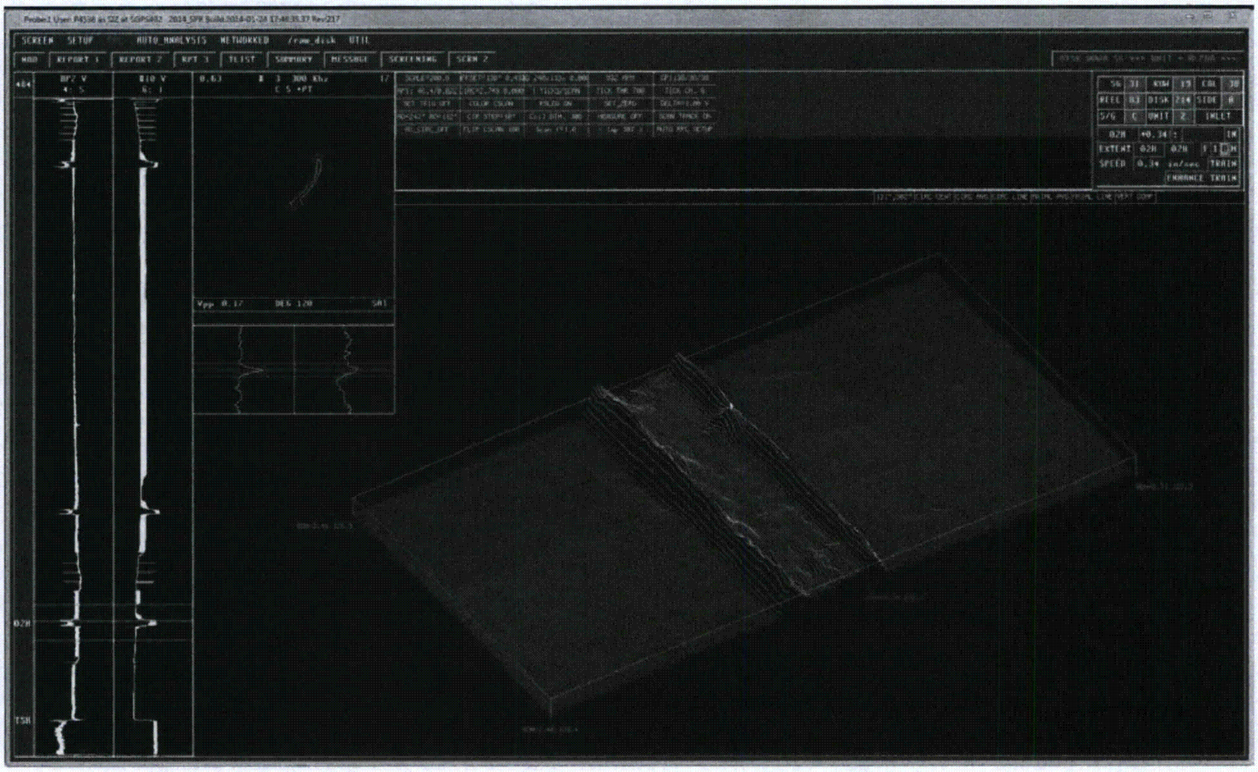


Figure 3-32: In-Generator +Point Probe – R19C38-3B (02H) – Top – SAI

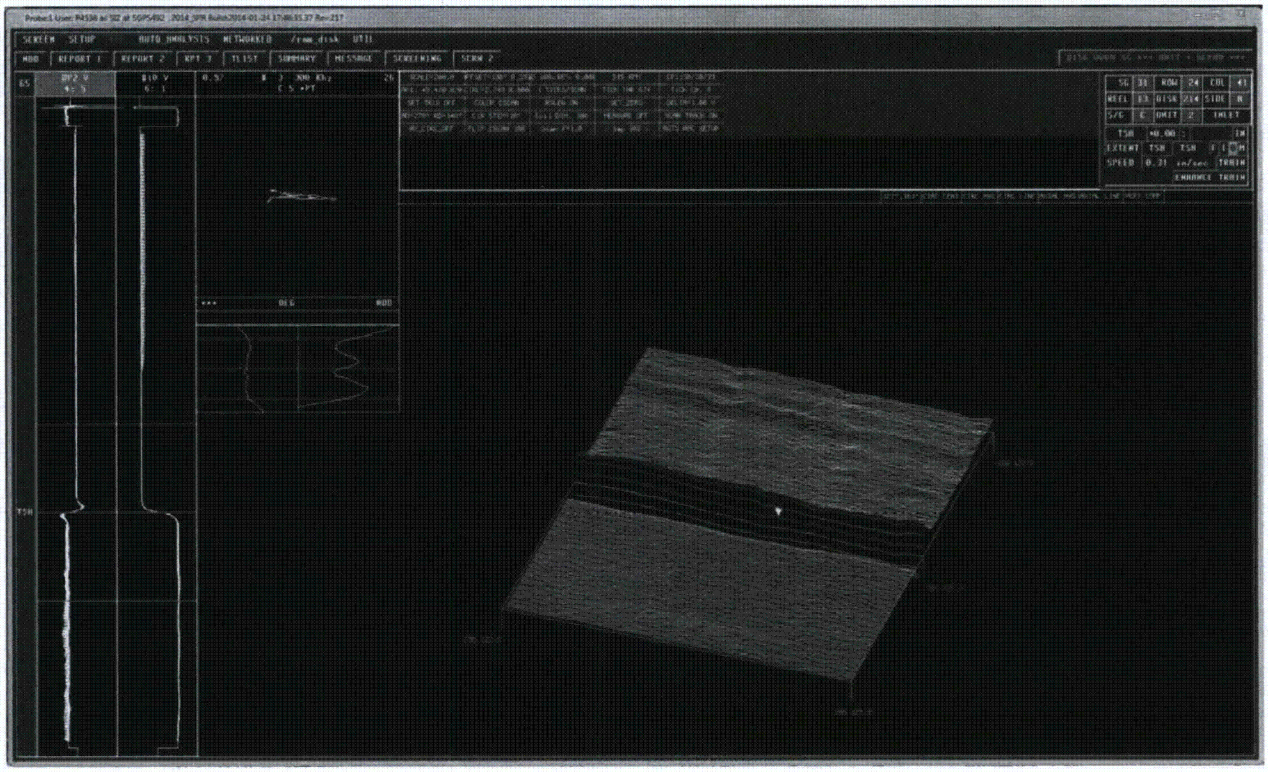


Figure 3-33: In-Generator +Point Probe – R24C41-1B TSH – NDD

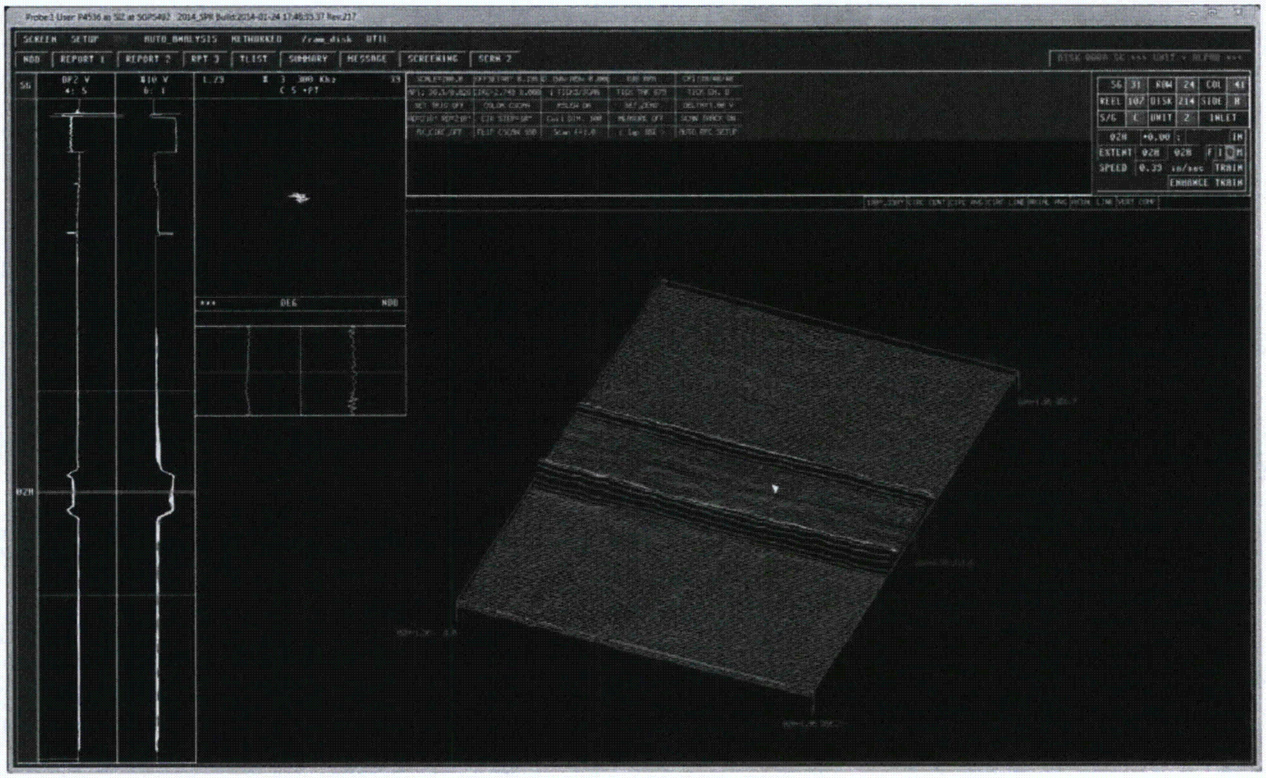


Figure 3-34: In-Generator +Point Probe – R24C41-3B (02H) – NDD

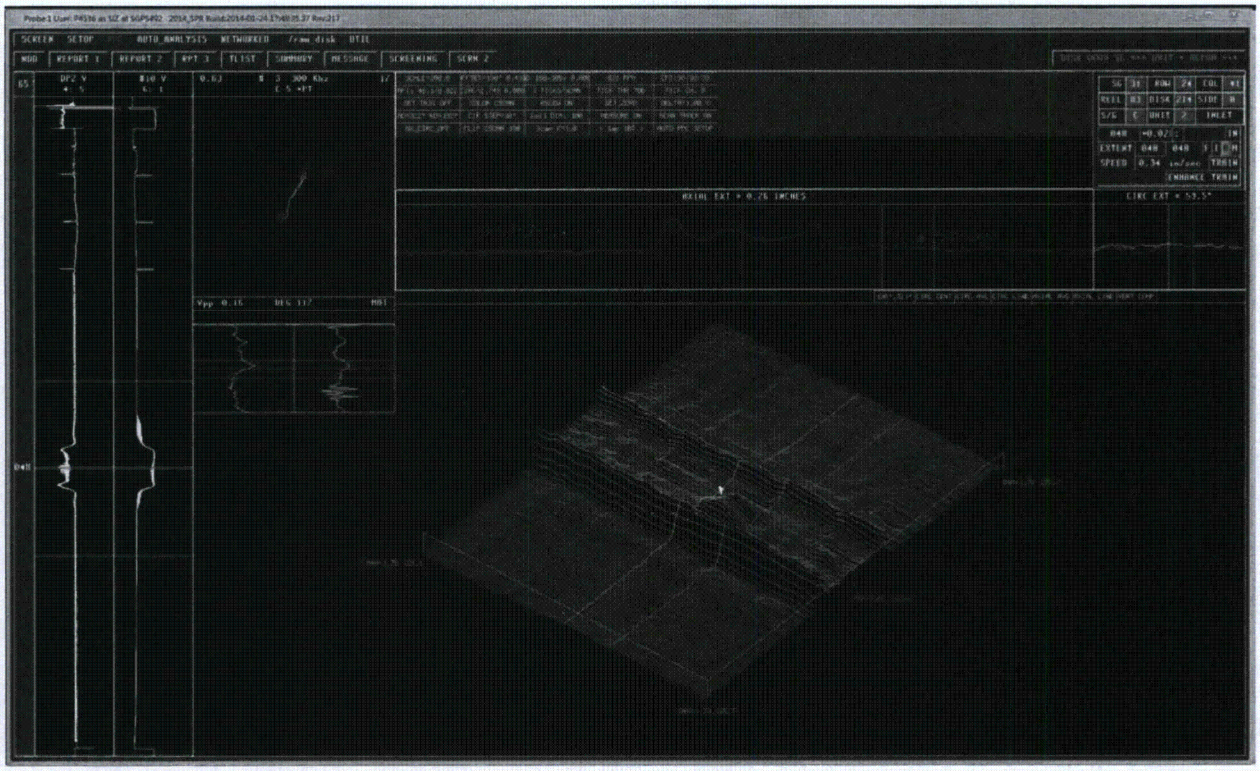


Figure 3-35: In-Generator +Point Probe – R24C41-6B (04H) – Ligament # 1 - MAI

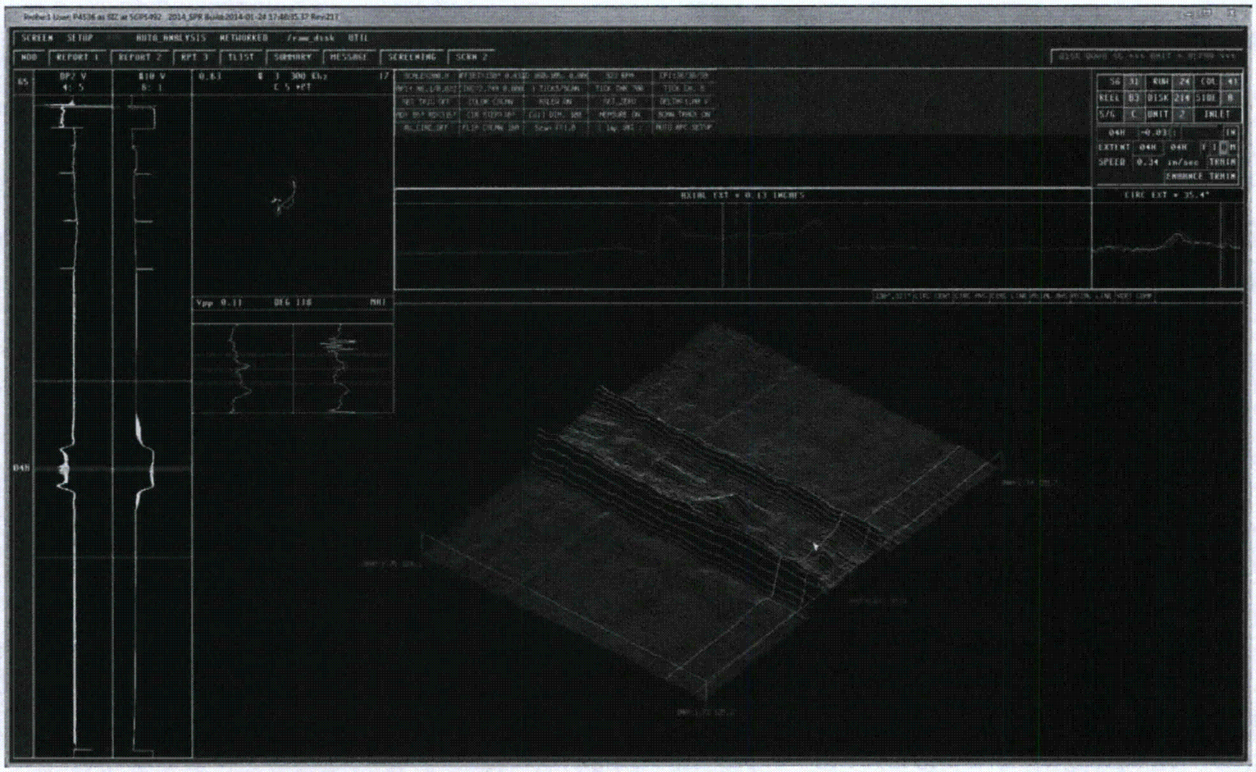


Figure 3-36: In-Generator +Point Probe – R24C41-6B (04H) – Ligament # 2 – MAI