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U.S. Nuclear Regulatory Commission
ATTN.: Document Control Desk
Washington, D.C. 20555

Joseph M. Farley Nuclear Plant
Eddy Current Guidelines for Steam Generator Inspections

Gentlemen:

By letter dated December 9, 1993, Southern Nuclear committed to provide revised eddy current guidelines for use with the interim plugging criteria during the upcoming Unit 1 outage. The eddy current guidelines are attached for your information. These guidelines, referred to as Appendix A, provide probe specifications, calibration requirements, specific acquisition and analysis criteria, and flaw recording guidelines to be used in the inspection of the steam generators.

These eddy current guidelines are extremely detailed. They contain the eddy current data acquisition and analysis criteria based on current bobbin coil and rotating pancake coil probe technology. In that equipment and analysis techniques are making rapid advances which can significantly improve steam generator tube NDE analysis, revisions to the guidelines may be required in order to enhance inspections. However, the latest inspection guidelines are always available for inspection at Farley Nuclear Plant. Furthermore, field bobbin indication voltage measurements will be obtained in a manner which results in voltage calls which are consistent with those used in development of the interim plugging criteria.

It should be noted that these guidelines are specific to Farley Nuclear Plant. If possible, all examples/figures used in the guidelines were obtained from the Farley steam generators. Furthermore, the applicability of some sections, e.g., copper interference, alloy property changes, dent interference, or the discussion on unusual phase angle indications, on a generic basis is unknown.

If there are any questions, please advise.

Respectfully submitted,

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DM Morey

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REM/clt:APPENA.DOC
Attachment

cc: Mr. S. D. Ebneter
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APPENDIX A
NDE DATA ACQUISITION AND ANALYSIS GUIDELINES

A.1 INTRODUCTION

This appendix contains eddy current guidelines which provide direction for application of the alternate repair limits for ODSCC at TSP intersections. The procedures for eddy current testing using bobbin coil and rotating pancake coil (RPC) techniques are summarized. The procedures given apply to the bobbin coil inspection, except as explicitly noted for RPC inspection. The methods and techniques detailed in this appendix are requisite for Farley implementation of the alternate repair limit and are to be incorporated in the applicable inspection and analysis procedures. The following sections define specific acquisition and analysis parameters and methods to be used for the inspection of the steam generator tubing.

A.2 DATA ACQUISITION

The Farley 1 and 2 steam generators utilize 7/8" OD x 0.050" wall, Alloy 600 mill-annealed tubing. The carbon steel support plates are designed with drilled holes.

A.2.1 Probes

<u>Bobbin Coil Probes</u>

Eddy current equipment used shall be the ERDAU (Echoram Tester), Zetec MIZ-18 or other equipment qualified for steam generator examination. To maximize consistency with laboratory data, differential bobbin probes with the following parameters shall be used.

The bobbin probe diameter shall be optimized to provide the largest practical fill factor for the tubes inspected:

Nominal Tube ID: 0.775"
Primary Probe Size: 0.720"
Alternate Probe Sizes: 0.640" - 0.740"
Fill Factor: 56% - 86%

The primary probe size should be used whenever the tube can be inspected with the 0.720" diameter probe. Alternate probe sizes can be used when specific tubes cannot be fully inspected with the 0.720" probe, such as tubes with sleeves at TSP intersections and small radius tubes sleeved in the tubesheet region. Larger probe diameters than 0.720" are generally acceptable but, for data consistency, should only be used when it has been demonstrated that the larger probe diameter improves the inspection at other regions of the S/Gs than TSP intersections. For all probe diameters, the centering devices must provide stable positioning within the nominal tube I.D. to minimize the variability of the probe response as measured with the four-hole wear standard. Alternate probes must have voltage normalization at the 20% ASME holes in the same manner as the 0.720" probe and must meet the acceptance criteria utilizing the probe wear standard (see Section A.2.2 to A.2.5).

Figure A-1 illustrates the equivalence of responses obtained with bobbin probes of various sizes relative to those obtained with the reference 0.720" bobbin. It has been found that the use of bobbin probes smaller in diameter than the reference 0.720" probe, but calibrated to the APC amplitude for 20% holes on an ASME standard, results in conservative signal responses. Plant L data taken with 560 mil or 580 mil bobbin probes as well as with the reference 720 mil probe yielded the following correlation for 46 data points:

$$560/580 \text{ voltage} = 0.47 + 1.07 \times (720 \text{ voltage}).$$

Similarly 21 support plate indications tested in Plant A with 640 mil probes calibrated to the APC voltages also yielded a conservative result:

$$640 \text{ voltage} = 1.20V\ (720 \text{ voltage}).$$

Each probe shall employ two bobbin coils, each 60 mils long with 60 mils between the coils (center to center spacing equal to 120 mils). Either magnetically biased or non-biased coils may be employed. Table A-1 presents the behavior of 0.720" bobbin probes for an ASME standard, a tube support plate simulation, the 4 hole wear standard and an EDM (electron discharge machined) notch standard for both coil configurations. There is no significant difference in the amplitudes of the responses from non-biased or magnetically biased probes for any of the discontinuities tested. Similar results were reported on pulled tube specimens from Plant R as shown as Table A-2.

Rotating Pancake Coil Probes

The pancake coil diameter shall be $\leq$0.125". While any number coil (i.e., 1, 2 or 3-coil) probe can be utilized, it is recommended that if a 3-coil probe is used, any voltage measurements should be made with the probe's pancake coil rather than its circumferential or axial coil. The maximum probe pulling speed shall be $\approx$0.2 in./sec for the 1-coil or 3-coil probe, or 0.4 in./sec for the 2-coil probe. The maximum rotation speed shall be $\approx$300 rpm; this would result in a pitch of $\approx$40 mils for the 3 coil probe.

A.2.2 Calibration Standards

Bobbin Coil Standards

To provide IPC implementation at Farley consistent with the development and analyses of the supporting data base and with prior NRC-approved IPC applications, a probe wear standard to guide probe replacement and ASME standards calibrated against the reference laboratory standard are to be utilized.

The bobbin coil calibration standard shall contain:

- Four 0.033" diameter through wall holes, 90° apart in a single plane around the tube circumference. The hole diameter tolerance shall be $\pm$0.001".

- One 0.109" diameter flat bottom hole, 60% through from OD.

- One 0.187" diameter flat bottom hole, 40% through from the OD.

- Four 0.187" diameter flat bottom holes, 20% through from the OD, spaced 90° apart in a single plane around the tube circumference. The tolerance on hole diameter and depth shall be $\pm$0.001".

- A simulated support ring, 0.75" thick, comprised of SA-285 Grade C carbon steel or equivalent.

- This calibration standard will have been calibrated against the reference standard used for the APC laboratory work. Voltages reported for IPC/APC applications shall include the cross calibration differences between field and laboratory standard.

- A probe wear standard for monitoring the degradation of probe centering dev:ces leading to off-center coil positioning and potential variations in flaw amplitude responses. This standard shall include four through wall holes, 0.067" in diameter, spaced 90° apart around the tube circumference with an axial spacing such that signals can be clearly distinguished from one another (see Section A.2.3).

RPC Standard

The RPC standard shall contain:

- Two axial EDM notches, located at the same axial position but 180° apart circumferential, each 0.006" wide and 0.5" long, one 80% and one 100% through wall from the OD.

- Two axial EDM notches, located at the same axial position but 180° apart circumferentially, each 0.006" wide and 0.5" long, one 60% and one 40% through wall from the OD.

- Two circumferential EDM notches, one 50% throughwall from the OD with a 75° (0.57") arc length, and one 100% throughwall with a 26° (0.20") arc length, with both notches 0.006" wide.

- A simulated support segment, 270° in circumferential extent, 0.75" thick, comprised of SA-285 Grade C carbon steel or equivalent.

The center to center distance between the support plate simulation and the nearest slot shall be at least 1.25". The center to center distance between the EDM notches shall be at least 1.0". The tolerance for the widths and depths of the notches shall be $\pm$0.001". The tolerance for the slot lengths shall be $\pm$0.010".

A.2.3 Application of Bobbin Coil Probe Wear Standard

A calibration standard has been designed to monitor bobbin coil probe wear (Figure A-2). During steam generator examination, the bobbin coil probe is inserted into the wear monitoring standard; the initial (new probe) amplitude response from each of the four holes is determined and compared on an individual basis with subsequent measurements. Signal amplitudes or voltages from the individual holes must remain within 15% of their initial amplitudes for an acceptable probe wear condition. If this condition is not satisfied for all four holes, then the probe must be replaced. If any of the last probe wear standard signal amplitudes prior to probe replacement exceed the +/- 15% limit, say by a value of X%, then any indications measured since the last acceptable probe wear measurement that are within X% of the plugging limit must be reinspected with the new probe. For example, if any of the last probe wear signal amplitudes prior to probe replacement were 17% above or below the initial amplitude, then indications that are within 2% (17% - 15%) of the plugging limit must be reinspected with the new probe. Alternatively, the voltage criterion may be lowered to compensate for the excess variation; for the case above, amplitudes ≥0.98 times the voltage criterion could be subject to repair.

A.2.3.1 Placement of Wear Standards

Under ideal circumstances, the incorporation of a wear standard in line with the conduit and guide tube configuration would provide continuous monitoring of the behavior of bobbin probe wear. However, the curvature of the channelhead places restrictions on the length of in line tubing inserts which can be accommodated. The spacing of the ASME Section XI holes and the wear standard results in a length of tubing which cannot be freely positioned within the restricted space available. The flexible conduit sections inside the channelhead, together with the guide tube, limit the space available for additional in line components. Voltage responses for the wear standard are sensitive to bending of the leads, and mock up tests have shown sensitivity to the robot end effector position in the tubesheet, even when the wear standard is placed on the bottom of the channelhead. Effects such as bending of the probe leads can result in premature probe replacement. Wear standard measurements must permit some optimization of positions for the measurement and this should be a periodic measurement for inspection efficiency. The pre-existing requirement to check calibration using the ASME tubing standard is satisfied by periodic probing at the beginning and end of each probe's use as well as at four hour intervals. This frequency is adequate for wear standard purposes as well. Evaluating the probe wear under uncontrollable circumstances would present variability in response due to channelhead orientations rather than changes in the probe itself.

A.2.4 Acquisition Parameters

The following parameters apply to bobbin coil data acquisition and should be incorporated in the applicable inspection procedures to supplement (not necessarily replace) the parameters normally used.

Test Frequencies

This technique requires the use of 400 kHz and 100 kHz test frequencies in the differential mode. It is recommended that the absolute mode also be used, at test frequencies of 100 kHz and 10 kHz. The low frequency (10 kHz) channel should be recorded to provide a positive means of verifying tube support plate edge detection for flaw location purposes. The 400 kHz channel or the 400/100 kHz mix are also used to assess changes in signal amplitudes for the probe wear standard as well as for flaw detection. Bobbin coil frequencies should include 400, 200, 100 and 10 kHz.

RPC frequencies should include 400 kHz, 300 kHz and 10 kHz.

Digitizing Rate

A minimum bobbin coil digitizing rate of 30 samples per inch should be used. Combinations of probe speeds and instrument sample rates should be chosen such that:

$$\frac{\text{Sample Rate (samples/sec.)}}{\text{Probe Speed (in./sec.)}} \geq 30 \text{ (samples/in.)}$$

Spans and Rotations

Spans and rotations can be set at the discretion of the user and/or in accordance with applicable procedures, but all TSP intersections must be viewed at a span setting one-half or less than that which provides 3/4 full screen amplitude for 4 x 20% holes with bobbin probes and 1/10 or less than the corresponding span for 0.5" throughwall slot (EDM notch) with RPC probes.

Mixes

A bobbin coil differential mix is established with 400 kHz as the primary frequency and 100 kHz as the secondary frequency, and suppression of the tube support plate simulation should be performed. Complementary information may be obtained from a 200 kHz/100 kHz mix; e.g., influence of dents at TSP's can be inferred from the difference with the 400 kHz/100 kHz mix.

A.2.5 Analysis Parameters

This section discusses the methodology for establishing bobbin coil data analysis variables such as spans, rotations, mixes, voltage scales, and calibration curves. Although indicated depth measurement may not be required to support an alternative repair limit, the methodology for establishing the calibration curves is presented. The use of these curves is recommended for consistency in reporting and to provide compatibility of results with subsequent inspections of the same steam generator and for comparison with other steam generators and/or plants.

Rotation

The signal from the 100% through wall hole at 400 kHz should be set to 40° ($\pm$1°) with the initial signal excursion down and to the right during probe withdrawal. The signal from the probe motion for the 400/100 kHz differential mix should be set to horizontal with the initial excursion of the 100% through wall hole signal going down and to the right during probe withdrawal.

Voltage Scale

1) Bobbin - The peak-to-peak signal amplitude of the sig[illegible]m the four 20% OD flaws should be set to produce a field voltage equivalent to that obtained for the EPRI lab standard. The EPRI laboratory standard normalization voltages are 4.0 volts at 400 kHz for 20% ASME holes and 2.75 volts at 400/100 kHz mix for 20% ASME holes. The field standard will be calibrated against the laboratory standard using a reference laboratory probe to establish voltages for the field standard that are equivalent to the above laboratory standard. These equivalent voltages are then set on the field standard to establish the calibration voltages. Voltage normalization for the specific standard in the 400/100 mix is recommended to minimize analyst sensitivity in establishing the mix.

2) RPC - The RPC amplitude shall be set to 20 volts for the 0.5 inch throughwall notch at 400 kHz and 300 kHz; i.e., the amplitude shall be set to 20 volts for each channel.

Calibration Curve

For the 400 kHz differential channel, establish a curve using measured signal phase angles in combination with the "as-built" flaw depths for the 100%, 60%, and 20% flaws on the calibration standard. The "as read" depth of the drilled holes should be determined from the 400 kHz differential channel. This should be accomplished by setting the phase angle of the 100% drilled holes to 40° and then determining the "as read" depth of the 60% and 20% drilled holes. These "as read" depths should then be employed for the setup of all phase angle calibration curves. For the 400/100 kHz differential mix channel, establish a curve using measured signal phase angles in combination with the "as-built" flaw depths for the 100%, 60%, and 20% flaws on the calibration standard.

A.2.6 Analysis Methodology

Bobbin coil indications attributable to ODSCC at support plates are quantified using the Mix 1 (400 kHz/100 kHz) data channel. This is illustrated with the example shown in Figure A-3. The 400/100 kHz mix channel and other channels appropriate for flaw detection (400 kHz, 200 kHz) can be used to locate the indication of interest within the support plate signal. The largest amplitude portion of the lissajous signal representing the flaw should be measured using the 400/100 kHz Mix 1 channel to establish the peak-to-peak voltage, shown as the final dot placement in Figures A-3 to A-5. Initial placement of the dots for identification of the flaw may be performed from the raw frequencies as shown in Figures A-3 to A-5, but the final peak-to-peak measurements must be performed on the Mix 1 lissajous signal to include the full flaw segment of the signal. It may be necessary to iterate the position of the dots between the identifying frequency data (e.g., 400 kHz) and the Mix 1 data to assure proper placement of the dots. As can be seen in Figures A-4 and A-5, failure to do so can significantly change the amplitude measurement of Mix 1 due to the interference of the support plate signal in the raw frequencies. The voltage measured from Mix 1 is then entered as the analysis of record for comparison with the repair limit voltage.

To support the uncertainty allowances maintained for the plugging criterion, the difference in amplitude measurements between independent analysts for each indication will be limited to 20%. If the voltage values called by the independent analysts deviate by more than 20% and one or both of the calls exceeds the voltage repair criterion, resolution by the lead analyst will be performed. These analyses result in enhanced confidence that the reported voltage departs from the correct call by no more than 20%.

A.2.7 Reporting Guidelines

The reporting requirements identified below are in addition to any other reporting requirements specified by the user.

<u>Minimum Requirements</u>

Flaw signals in the 400/100 mix channel at the tube support plate intersections <u>must</u> be reported. Flaw signals, however small, must be reported to support accident condition leak rate analyses and for historical purposes to provide an assessment of the overall condition of the steam generator(s).

Additional Requirements

For each reported indication, the following information should be recorded:

Tube identification	(row, column)
Signal amplitude	(volts)
Signal phase angle	(degrees)
Indicated depth	(%) †
Test channel	(ch#)
Axial position in tube	(location)
Extent of test	(extent)

† It is recommended that an indicated depth be reported as much as possible rather than some letter code. While this measurement is not required to meet the alternate repair limit, this information might be required at a later date and/or otherwise be used to develop enhanced analysis techniques.

RPC reporting requirements should include a minimum of: type of degradation (axial, circumferential or other), maximum voltage, phase angle, crack lengths, and location of the center of the crack within the TSP. The crack axial center may not coincide with the position of maximum amplitude. For IPC applications, locations which do not exhibit flaw-like indications in the RPC isometric plots may continue in service, except that all intersections exhibiting flaw-like bobbin behavior and bobbin amplitudes in excess of an upper voltage limit typical of the full APC repair limit (defined by approved IPC criteria) must be repaired, notwithstanding the RPC analyses. RPC isometrics should be interpreted by the analyst to characterize the signals observed; only featureless isometrics are to be reported as NDD. Signals not interpreted as flaws include dents, lift off, deposits, copper, magnetite, etc.; these represent "non-relevant" conditions which do not impact tube integrity as reported.

A.3 DATA EVALUATION

A.3.1 Use of 400/100 Differential Mix for Extracting the Bobbin Flaw Signal

In order to identify a discontinuity in the composite signal as an indication of a flaw in the tube wall, a simple signal processing procedure of mixing the data from the two test frequencies is used which reduces the interference from the support plate signal by about an order of magnitude. The test frequencies most often used for this signal processing are 400 kHz and 100 kHz for 50 mil wall Inconel-600 tubing. The processed data is referred to as 400/100 mix channel data. This procedure may also reduce the interference from magnetite accumulated in the crevices. Any of the differential data channels including the mix channel may be used for flaw detection (though the 100 kHz channel is subject to influence from many different effects), but the final evaluation of the signal detection, amplitude and phase will be made from the 400/100 differential mix channel. Upon detection of a flaw signal in the differential mix channels, confirmation from other raw channels is not required. The voltage scale for the 400/100 differential channel should be normalized as described in Section A.2.5.

With a typical bobbin calibration (Figure A-6), flaw signals in the upper half of the impedance plane (0° to 180°) are assumed to be I.D. in origin for phase angles from 0° to the angle corresponding to the 100% hole — typically around 35° in the 400/100 mix; phase angles from 35° to 180° are attributed to O.D. origin. Industry practice provides 10° variation about 0° or 180° due to redundancy of shallow flaws and probe wobble or denting, i.e., lift off signals. Thus, flaw signals are expected to be observed in the 10° - 170° range. Examination of the calibration curve shows that the 0% O.D. depth intercept occurs at phase angles below 170°, usually in the 125° - 150° range. Since maximum ODSCC depth is not well represented by the phase angle measurement, especially for small amplitude signals, some flaw-like signals may exhibit phase angles at or beyond the 0% intercept but less than or equal to 170° (Figures A-7 and A-8). Industry practice regards these signals as non-reportable, and RPC testing of these signals at plants such as Farley and Plant D has not confirmed the presence of detectable cracks. Nevertheless, inasmuch as these signals may represent ODSCC, they should be reported as O.D. indications of unmeasurable depth.

In some cases it has been observed (Figure A-9) that I.D. oriented flaw signals, those with phase angles ≥ 10° but ≤ 35° (100% hole phase angle in the 400/100 mix), are encountered in non-dented support plate intersections. It has been confirmed at Farley-2 and at Plant L from tube pull information or from RPC testing (Figure A-10) that these apparent I.D. origin bobbin signals correlate well with ODSCC. To assure appropriate disposition of these signals within the alternate repair framework, these signals will be reported in the same fashion as those which present clear O.D. phase information.

The Farley reporting guidelines require that TSP flaw signals with I.D. oriented phase angles be reported using the possible indication (PI) designation as is done for the measurable O.D. oriented indications. For the unmeasurable O.D. signals (phase angle ≥ 0% intercept), the designation applied is UOA (unusual O.D. phase angle). All PI's with amplitudes > the voltage threshold for RPC inspection, 1.5 volts, will be subject to RPC testing.

PI's continued in service in prior years because of acceptable voltage or RPC NDD results may, upon re-inspection in subsequent outages, be evaluated as not exhibiting flaw characteristics. These signals will be designated INR (indication not reportable) but the location, phase angle, and amplitude will be recorded to facilitate year to year comparisons and growth rate determinations.

This evaluation procedure requires that there is no minimum voltage for flaw detection purposes and that all flaw signals, however small, be identified. The intersections with flaw signal (PI) amplitudes greater than 1.5 volts will be inspected with RPC in order to confirm the presence of ODSCC. Although the signal voltage is not a measure of the flaw depth, it is an indicator of the tube burst pressure when the flaw is identified as axial ODSCC with or without minor IGA. UOA and INR signals will be included in the RPC sampling plan with emphasis on sample RPC inspection of indications greater than the voltage repair limit.

This procedure using the 400/100 mix for reducing the influence of support plate and magnetite does not totally eliminate the interference from copper, alloy property change or dents. These are discussed below.

A.3.2 Amplitude Variability

Figures A-11 and A-12 illustrate how significant amplitude differences between two analysts measurements might arise: Analyst 1 (Figure A-11) has made a more conservative estimate by placing his measurement dots where the differential phase in all channels trends out of the flaw plane, while flaw plane phase angles appear beyond the upper dot placement in Analyst 2's graphic (see Figure A-12). Analyst 1's conservative call produces a peak-to-peak voltage (1.72V) one-third (1/3) greater than Analyst 2's result. Figure A-12 represents an example in which the placement of the max-rate dots, which establish the maximum estimated flaw depth, under-estimates the apparent flaw-related peak-to-peak voltage. The correct placement (Figure A-11) also corresponds to the maximum voltage measurement on the 400 kHz raw frequency data channel.

In some cases, it will be found that little if any definitive help is available from the use of the raw frequencies. Such examples are shown in Figure A-13 and A-14. Consequently, the placement of the measurement dots must be made completely on the basis of the Mix 1 channel lissajous figure as shown in the lower right of the graphic. An even more difficult example is shown in Figure A-15. The logic behind the placement of the dots on Mix 1 is that sharp transitions in the residual support plate signals can be observed at the locations of both dots. This is a conservative approach and should be taken whenever a degree of doubt as to the dot placement exists.

The source of error becomes more noticeable when the data involves complicating factors or interferences which make the process of flaw identification more difficult; the contrast between tubes which exhibit signs of minor denting in the support plates and tubes which are essentially free from denting present such circumstances. How denting affects flaw detection is described in Section A.3.5.

By employing these techniques, identification of flaws is improved and that conservative amplitude measurements are promoted. The Mix 1 traces which result from this approach conform to the model of TSP ODSCC which represents the degradation as a series of microcrack segments axially integrated by the bobbin coil; i.e., short segments of changing phase direction represent changes in average depth with changing axial position. This procedure is to be followed for reporting voltages for the plugging criteria of this report. This procedure may not yield the maximum bobbin depth call. If maximum depth is desired for information purposes, shorter segments of the overall crack may have to be evaluated to obtain the maximum depth estimate. However, the peak-to-peak voltages as described herein must be reported, even if a different segment is used for the depth call.

The Farley site guidelines for reporting EC indications require that indications reported by any of the independent analyses will cause the particular location to be identified with an indication. If the largest voltage call exceeds the voltage repair limit and another analysis is NDD, reporting as an indication or not will be determined by a resolution analyst. If the amplitude measurements reported from the analyses differ, the larger of the measurements will control unless the lead analyst (primary vendor Level III) clearly establishes that the higher amplitude measurement is erroneous. Lead analyst review is required on indications exceeding the voltage repair limit for which the reported voltages differ by more than 20%. Exercise of this review by the lead analyst will be denoted by use of LAR (Lead Analyst Review) as a comment associated with the data base entry for that indication. Each analyst's original call will be preserved on his individual report and stored on the permanent record optical disk for the inspection. This practice limits the uncertainty attributable to analyst uncertainty to 20%.

A.3.3 Copper Interference

In situations where significant copper interference in the eddy current data is noted, the eddy current technique could become unreliable. This results from the unpredictability of the amount and morphology of copper deposits on the tubes which may be found in operating steam generators. The above observation is true both for bobbin and RPC or any other eddy current probe. However, significant copper interference does not occur in the support plate crevice regions of Farley Unit 1 and 2. This is confirmed by destructive examination of the support plate intersections on tubes pulled from Farley Unit 1 and 2. No plated copper was found on the tube OD within the support plate crevice, although some minor plated copper patches outside the crevice region were sometimes observed.

Inspections with RPC and bobbin probes have shown good correlation for flaw amplitudes exceeding 1.0 volt; i.e., more than 50% of the bobbin signals identified have been confirmed to exhibit flaws to the RPC probe. This suggests that spurious signals from conductive deposits do not result in excessively high false call rates. Furthermore, signals judged as NDD with the bobbin guidelines have been confirmed to be free of RPC detectable flaws. Copper is a concern for NDE only when plated directly on the tube surface in elemental form. Copper particles with the sludge in the crevice do not significantly influence the eddy current response. To Westinghouse's knowledge, no pulled tubes have been identified with copper deposits on the tube at the TSP intersections — in contrast with free span tubing. Copper alloys previously used in the secondary system have been replaced with titanium or stainless steel heat transfer tubing. Thus, it is not expected that copper interference will significantly influence the TSP signals in the Farley S/Gs. If copper interference is observed at Farley 1 or 2, the existing rules and procedures for complying with the technical specifications plugging limit based on depth of wall penetration will apply.

A.3.4 Alloy Property Changes

This signal manifests itself as part of the support plate "mix residual" in both the differential and absolute mix channels. It has often been confused with copper deposit as the cause. Such signals are often found at support plate intersections of operating plants, as well as in the model boiler test samples, and are not necessarily indicative of tube wall degradation. Six support plate intersections from Farley 2, judged as free of tube wall degradation on the basis of the mixed differential channel using the guidelines given in Section A.2.5 and A.2.6 of this document, were pulled in 1989. Examples of the bobbin coil field data are shown in Figures A-16 through A-18. The mix residuals for these examples are between 2 and 3 volts in the differential mix channel and no discontinuity suggestive of a flaw can be found in this channel. All of them do have an offset in the absolute mix channel which could be construed as a possible indication. These signals persisted without any significant change even after chemically cleaning the OD and the ID of the tubes. The destructive examination of these intersections showed very minor or no tube wall degradation. Thus, the overall "residuals" of both the differential and absolute mix channels were not indications of tube wall degradation. One needs to examine the detailed structure of the "mix residual" (as outlined in Sections A.2.5 and A.2.6) in order to assess the possibility that a flaw signal is present in the residual composite. Similar offsets in the absolute channels have been observed at the top of the tubesheet in plants with partial length roll expansions; in such cases, destructive examination of sections pulled from operating plants have shown no indication of tube wall degradation. Verification of the integrity of intersections exhibiting alloy property or artifact signals is accomplished by RPC testing of a representative sample of such signals.

A.3.5 Dent Interference

There are essentially no corrosion induced dent signals of any significance at the support plate intersections of Farley Unit 2. A small population of original condition dents, mainly at the upper support plates, with voltages up to about 10-15 volts, are present; this is typical of the as-built condition of a steam generator, which may have random local dents ("dings"), some at support plate elevations. Farley Unit 1 has a small population of corrosion induced dents, Figure A-19, at the support plate intersections. These locations, when tested with bobbin probes, produce signals which are a composite of the dent signal plus other contributing effects such as packed magnetite, conductive deposits, alloy property change (artifacts) plus flaw signals if present and the support plate itself.

The 400/100 kHz (differential) support plate suppression mix reduces the support plate and the magnetite signals, but the resulting processed signal may still be a composite of the dent, artifact, and flaw signals. These composite signals represent vectorial combinations of the constituent effects, and as such they may not conform to the behavior expected from simple flaw simulations as a function of test frequency.

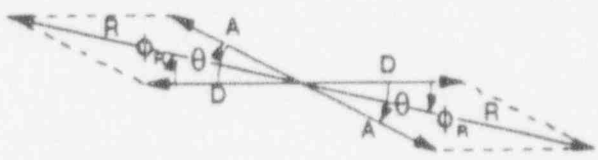
The average signal amplitude of the dent population in the most affected steam generator at Farley (S/G C in Unit 1) is 3.2 volts peak-to-peak; very few of the dents observed exceed 10 volts measured at the 400 kHz calibration settings. It can be seen that only a few hundred intersections (<1% of the tubes) exhibit TSP dents greater than 2 volts.

The effect of the dent on the detection and evaluation of a flaw signal depends on both the relative amplitudes of the flaw and dent signals and the relative spatial relationship between them. If the flaw is located near the center of the dent signal, interference with flaw detection may become insignificant, even for relatively large dent to flaw signal amplitude ratios. The flaw signal in a typical support plate dent in this event occurs mid-plane — away from the support plate edges where the dent signal has maximum voltage; thus the flaw in the middle section of the support plate shows up as a discontinuity in the middle of the composite signal. Some examples of such cases in the field data obtained from Farley 1 are shown in Figures A-20 to A-25 for dents with peak-to-peak amplitudes ranging from ~4 to 10 volts. The top pictures in these figures show the composite signal voltages; the pictures in the bottom half give the flaw voltages. For example, in Figure A-20, the dent voltage at 400 kHz is ~10.3 volts and the flaw signal voltage in the 400/100 kHz mix channel is ~1.3 volts. It can be observed from these figures that one can extract a flaw signal even when the signal to noise (S/N) ratio is less than unity. The question of S/N ratio requirements for the detection and evaluation of the flaw signal is answered by examination of

Figures A-20 to A-25. In all cases shown, S/N is less than 1, and the flaw signal can be detected and evaluated.

The greatest challenge to flaw detection due to dent interference occurs when the flaw signal occurs at the peak of the dent signal. Detection of flaw signals of amplitudes equal to or greater than 1.0 volt — the criterion associated with IPC confirmatory RPC testing — in the presence of peak dent voltages can be understood by vectorial combination of a 1.0 volt flaw signal across the range of phase angles associated with 40% (110 degrees) to 100% (40 degrees) through wall penetrations with dent signals of various amplitudes. It is easily shown that 1.0 volt flaw signals combined with dent signals up to approximately 5 volts peak-to-peak will yield resultant signals with phase angles that fall within the flaw reporting range, and in all cases will exceed 1.0 volt. All such signals with a flaw indication signal will be subjected to RPC testing. To demonstrate this, one-half the dent peak-to-peak voltage (entrance of exit lobe) can be combined with the 1.0 volt flaw signal at the desired phase angle. The inspection data shown in Figures A-20 through A-25 illustrates flaw detection and evaluation for flaws situated away from the peak dent voltages. The vector combination analysis shows that for moderate dent voltages where flaws occur coincident with dent entrance or exit locations, flaw detection at the 1.0 volt amplitude level is successful via phase discrimination of combined flaw/dent signals from dent only signals.

The vector addition model for axial cracks coincident with denting at the TSP edge is illustrated as follows:



where

R = Resultant Signal Amplitude
A = Flaw Signal Amplitude
D = TSP Dent Amplitude - one edge (Peak to Peak = 2D)
θ = Flaw Signal Phase Angle (100% = 40°; 40% ~ 110°)
ϕ_R = Phase Angle of Resultant Signal
and $R^2 = (D + A\cos\theta)^2 + (A\sin\theta)^2$
$\phi_R = \arctan(A\sin\theta/D + A\cos\theta)$

For dents without flaws, a nominal phase angle of 180° (0°) is expected. The presence of a flaw results in rotation of the phase angle to < 180° and into the flaw plane. A phase angle of 170° (10° away from nominal dent signal) provides a sufficient change to identify a flaw. For dents with peak-to-peak ampiitudes of 5 volts,. D = 2.5V and the minimum phase angle rotation (ϕ_R) for a 1.5V ODSCC flaw signal greater than 40% throughwall is predicted to be at least 15°, sufficiently distinguishable from the 180° (0°) phase angle associated with a simple dent. Such signals should be reported as possible flaws and subjected to RPC testing for final disposition.

Supplemental information to reinforce this phase discrimination basis for flaw identification can be obtained by examination of a 200 kHz/ 100 kHz mix channel; the dent response would be lessened while the OD originating flaw response is increased relative to the 400 kHz/100 kHz mix. RPC testing of indications identified in this fashion will confirm the dependability of flaw signal detection. A sample of intersections with dent voltages (phase angle 180° 0° +/- 10°) exceeding 5.0 volts will be RPC tested.

A.3.6 RPC Flaw Characterization

The RPC inspection of the intersections with bobbin coil flaw indications exceeding the voltage threshold is recommended in order to verify the applicability of the alternate repair limit. This is based on establishing the presence of ODSCC with minor IGA as the cause of the bobbin indications.

The signal voltage for the RPC data evaluation will be based on 20 volts for the 100% throughwall, 0.5" long EDM notch at all frequencies. The nature of the degradation and its orientation (axial or circumferential) will be determined from careful examination of the isometric plots of the RPC data. The presence of axial ODSCC at the support plate intersections has been well documented, but the presence of cellular corrosion which includes elements of circumferential ODSCC at the support plate intersections has also been established by tube pull in several plants. Figures A-26 to A-28 show examples of single and multiple axial ODSCC. Figure A-29 is an example of a circumferential indication related to ODSCC at a dented tube support plate location from another plant. If circumferential involvement results from circumferential cracks as opposed to multiple axial cracks, discrimination between axial and circumferential oriented cracking can be generally established for affected arc lengths greater than about 45 degrees to 60 degrees.

Pancake coil resolution is considered adequate for separation between circumferential and axial cracks. This can be supplemented by careful interpretation of 3-coil results. Circumferential cracking may occur in the Farley steam generators due to the presence of TSP denting. If a well defined circumferential indication is identified at a tube support plate location in the Farley steam generators (>60 degrees circumferential extent), guidelines for RPC interpretation will be reviewed and consideration given to supplemental inspection techniques for resolution of the degradation mode.

The isometric graphics which are produced to illustrate the distribution of signals in a TSP may sometimes exhibit distributed extents of flaw content not readily identified with the discrete axial indications associated with cracks; this may occur with or without the presence of crack signals. The underlying tubing condition represented by volumetric flaw indications is interpreted in the context of the relative sensitivity of various flaw types (pits, wastage/wear, IGA, distributed cracks) potentially present.

The response from pits of significant depth is expected to produce geometric features readily identifiable with small area to amplitude characteristics. When multiple pits become so numerous as to overlap in the isometric display, the practical effect is to mimic the response from wastage or wear at comparable depths. In these circumstances the area affected is generally large relative to the peak amplitudes observed.

The presence of IGA as a local effect directly adjacent to crack faces is expected to be indistinguishable from the crack responses and as such of no structural consequence. When IGA exists as a general phenomenon, the EC response is proportional to the volume of material affected, with phase angle corresponding to depth of penetration and amplitude relatively larger than that expected for small cracks. The presence of distributed cracking, e.g., cellular SCC, may produce responses from microcracks of sufficient individual dimensions to be detected but not resolved by the RPC, resulting in apparent volumetric responses similar to wastage and IGA.

For hot leg TSP locations, there is little industry experience on the basis of tube pulls that true volumetric degradation, i.e., actual wall loss or generalized IGA, actually occurs. Figure A-30 illustrates the RPC response from a Farley pulled tube in which closely spaced axial cracks (lower portion of Figure) produced an indication suggestive of a circumferential or volumetric condition. All cases reviewed for the APC show morphologies representative of ODSCC with varying density of cracks and penetrations but virtually no loss of material in the volumetric sense. Appendix C of EPRI Report NP-7480-L, Volume 1, Revision 1 provides a more detailed discussion of RPC response characteristics consistent with the APC data base. The available data in the report indicate that RPC responses $\leq 150°$ in azimuthal extent and >0.2 inch axial length are acceptable responses for RPC applications. For cold leg TSP locations, considerable experience has accrued that volumetric degradation in the form of wastage has occurred on peripheral tubes, favoring the lower TSP elevations.

Therefore, hot leg RPC volumetric flaw indications within the TSP intersections will be presumed to represent ODSCC, while only peripheral tube, lower TSP locations on the cold leg with RPC volumetric flaw indications will not be so characterized.

A.3.7 Confinement of ODSCC/IGA Within the Support Plate Region

In order to establish that a bobbin indication is within the support plate, the displacement of each end of the signal is determined relative to the support plate center. The field measurement is then corrected for field spread (look-ahead) to determine the true distance from the TSP center to the crack tip. If this distance exceeds one-half the support plate axial length (0.375"), the crack will be considered to have progressed outside the support plate. Per the repair criteria (Section 10) indications extending outside the support plate require tube repair or removal from service.

A.3.7.1 Crack Length Determination with RPC Probes

The measurement of axial crack lengths from RPC isometrics is presently a standard portion of the Farley EC interpretation practices. For the location of interest, the low frequency channel (e.g., 10 kHz) is used to set a local scale for measurement. By establishing the midpoint of the support plate response and storing this position in the 300 kHz and 400 kHz channels, a reference point for crack location is established. Calibration of the distance scale is accomplished by setting the displacement between the 10 kHz absolute, upper and lower support plate transitions, equal to 0.75 inch.

At the analysis frequency, either 300 kHz or 400 kHz, the ends of the crack indication are located using the slope-intercept method; i.e., the leading and trailing edges of the signal pattern are extrapolated to cross the null baseline (see Figure A-31). The difference between these two positions is the crack length estimate. The slope-intercept method, studied by Junker and Shannon,[1] utilizes the total impedance data profile to predict the actual crack length from pancake EC data. This technique, which is illustrated in Figure A-32, yields measurements which are less affected by the shape of the crack than does the amplitude threshold technique commonly used in field measurements. The measurements obtained consistently oversized the true crack length by approximately one coil diameter. Thus, for calculations using crack lengths, the field measured lengths should be adjusted for pancake coil diameter. Alternately, the number of scan lines indicating the presence of flaw behavior times the pitch of the RPC provides an estimate of the crack length which must be corrected for EC field spread. Figures A-33 and A-34 illustrate the identification of the first and last scan lines of the linear indication from which the length of the underlying flaw can be determined.

A.3.8 RPC Inspection Plan

The RPC inspection plan will include the following upon implementation of the APC repair limits:

- Bobbin voltage potential indications (PIs) greater than 1.5 volts.

[1] EPRI TR-101104, W. R. Junker and R. E. Shannon, August 1992

- A representative sample of 100 TSP intersections, as applicable, based on the following:

  1) Dented tubes at TSP intersections with bobbin dent voltages exceeding 5 volts.

  2) Artifact signals (alloy property changes) with amplitudes potentially masking flaw signals greater than 2.0 volts.

  3) Bobbin indications less than 1.5 volts for support of these indications as typical of ODSCC.

  4) Non-measurable depth (< 0%) indications (UOAs) with preference for amplitudes greater than 2.0 volts.

  5) Indications not reportable (INRs) with amplitudes greater than 2.0 volts.

Considerations for expansion of the RPC inspection would be based on identifying unusual or unexpected indications such as clear circumferential cracks. In this case, structural assessments of the significance of the indications would be used to guide the need for further RPC inspection.

A.3.8.1 3-Coil RPC Usage

Farley's standard practice allows for use of 3-coil RPC probes, incorporating a pancake coil, an axial preference coil, and a circumferential preference coil. Comparisons for ODSCC with bobbin amplitudes exceeding 1.0 volt have shown that the pancake coil fulfills the need for discrimination between axial and circumferential indications, when compared against the outputs of the preferred direction coils. Pancake coils have been the basis for reporting RPC voltages for model boiler and pulled tube indications in the APC database. These data permit semi-quantitative judgements on the potential significance of RPC indications. The requirement for a pancake coil is satisfied by the single coil, 2-coil, and 3-coil probes in common use for RPC inspections. Supplemental information, if needed, may be obtained from review of the preference coils on the 3-coil RPC if desired.

TABLE A-1

EFFECT OF MAGNETS ON RESPONSE OF ECHORAM BOBBIN PROBES
7/8" TUBING STANDARD 0.720 MIL PROBES
AVERAGE AMPLITUDES @ 400 kHz

	With Magnets	Without Magnets	Ratio With Magnets/Without Magnets
ASME			
4 x 20%	4.04	4.01	1.008
4 x 40%	3.42	3.42	1.000
4 x 60%	3.73	3.74	0.993
4 x 80%	3.92	3.94	0.995
4 x 100%	5.97	6.01	0.997
Support Plate	6.60	6.35	1.040
WEAR STANDARD			
100%	5.87	5.71	1.028
100%	5.83	5.84	0.998
100%	5.68	5.75	0.987
100%	5.86	5.65	1.032
0.5" EDM STANDARD			
20%	—	—	—
40%	0.78	0.79	0.988
60%	1.92	1.93	0.995
80%	2.61	2.61	1.000
100%	73.43	74.06	0.992

TABLE A-2

MAG BIAS VERSUS NON-MAG BIAS PROBES COMPARISON
PLANT R PULLED TUBES (SUPPORT PLATE SUPPRESSION MIX)

Mag Bias	Non-Mag Bias	% Change
PULLED TUBES (B&W): 3/4" TUBING, 550/130 KHZ MIX		
0.38	0.37	+2.7%
5.23	5.06	+3.4%
4.10	4.13	-0.1%
2.11	2.07	+1.9%
5.38	5.34	+0.1%
3.26	3.31	-1.5%
0.18	0.82	-1.2%
1.06	1.04	+1.9%
MACHINED HOLE (B&W): 3/4" TUBING, 550/130 KHZ MIX		
5.24	5.40	-3.0%
5.43	5.54	-2.0%
2.74	2.76	-0.1%
11.60	11.78	-1.5%
19.82	20.17	-1.7%
4.67	4.80	-2.7%

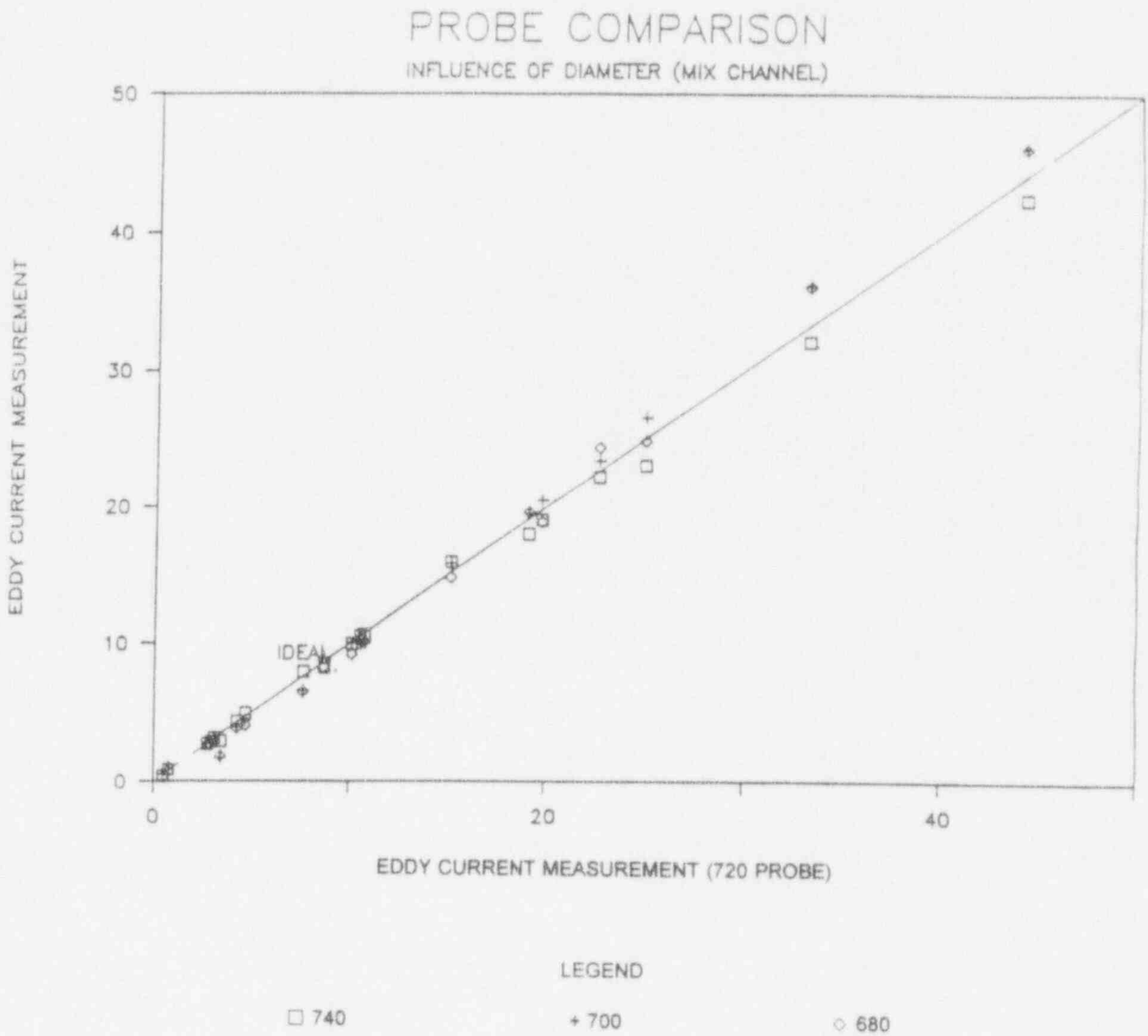


Figure A-1. Probe Comparison.

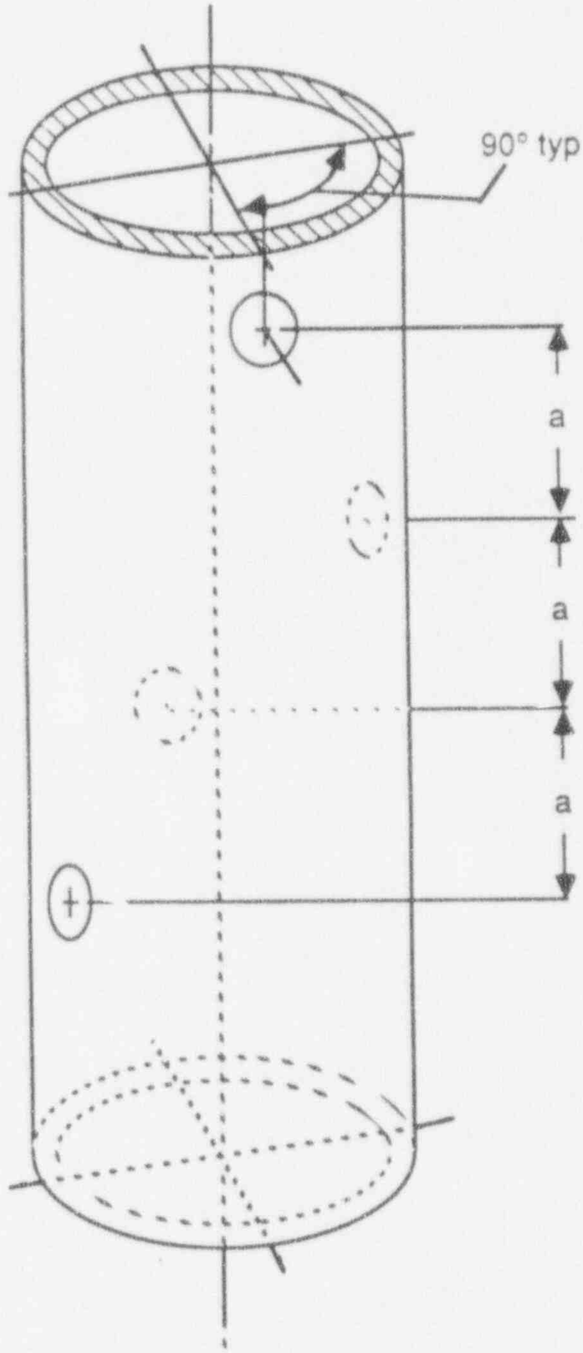


Figure A-2. Probe Wear Calibration Standard.

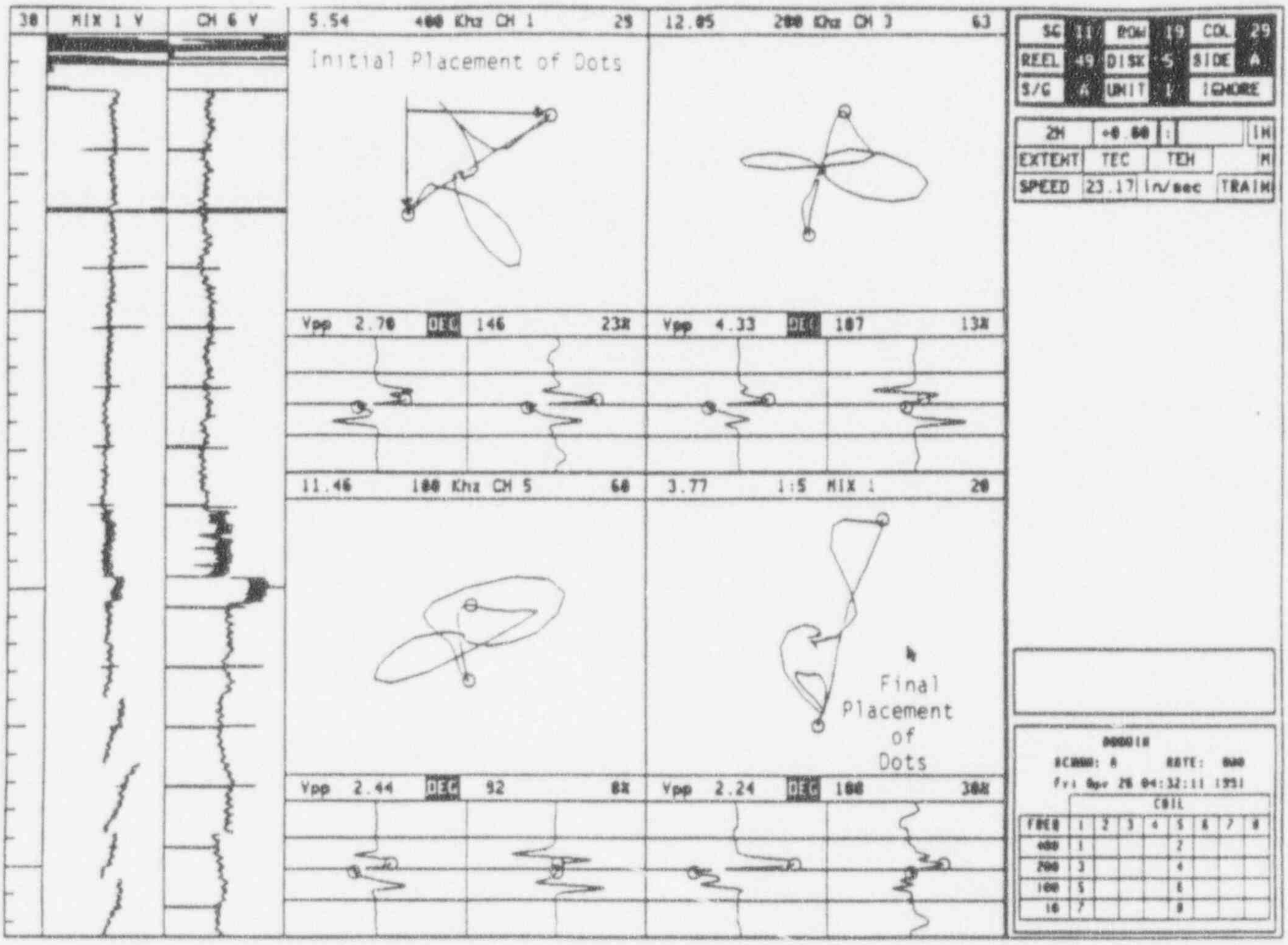


Figure A-3. Bobbin Coil Amplitude of ODSCC at TSP.

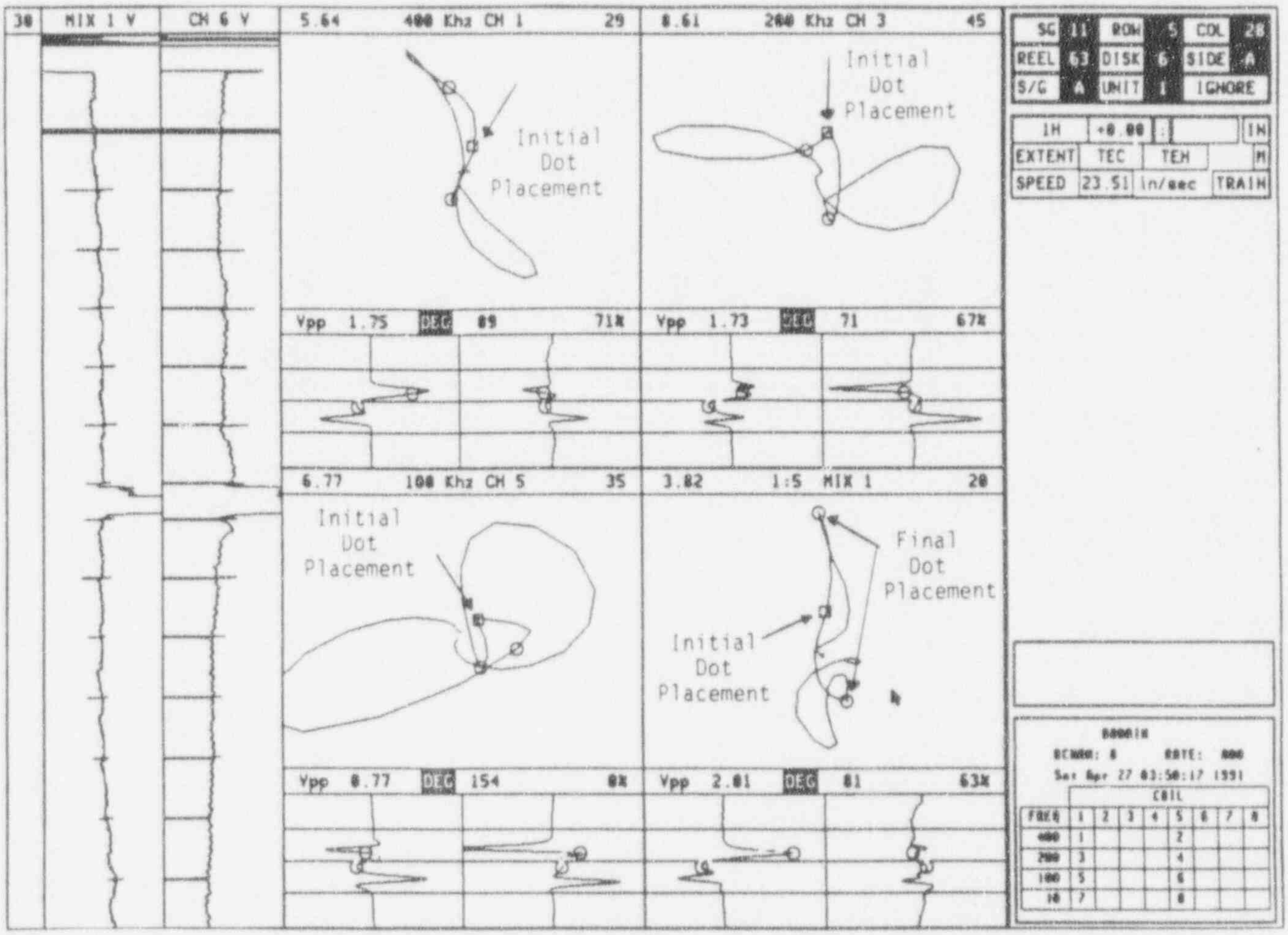


Figure A-4. Bobbin Coil Amplitude of ODSCC at TSP - Improper Identification of Full Flaw Segment.

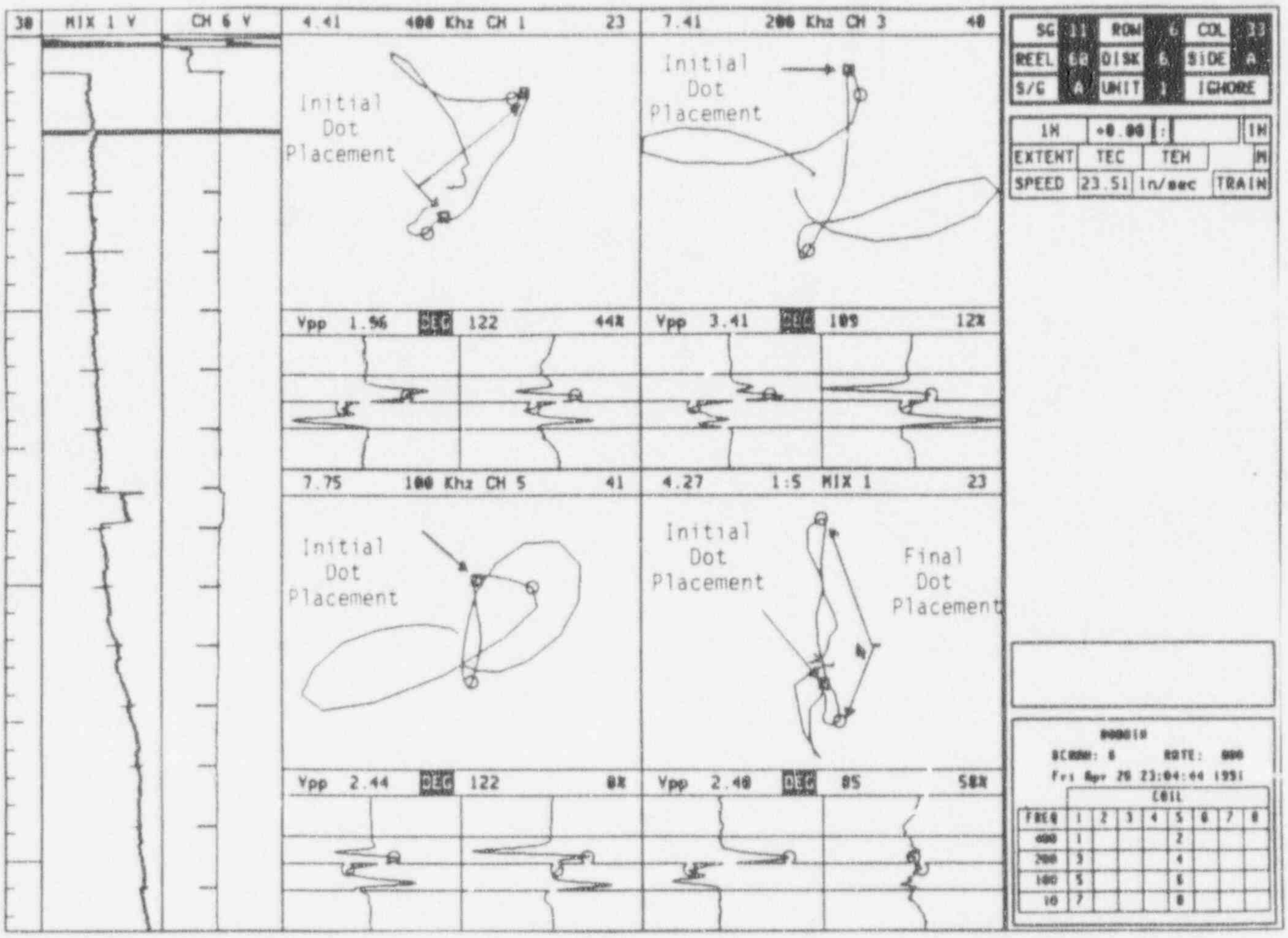
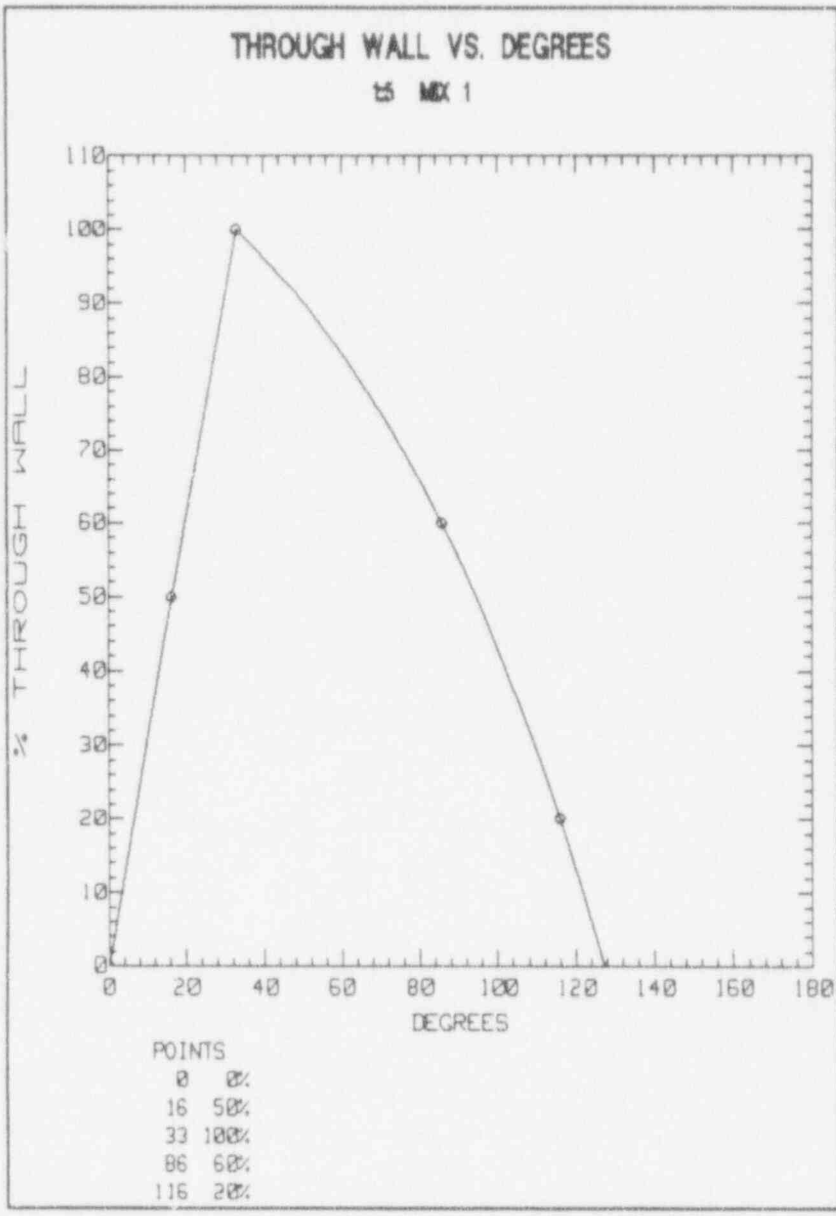


Figure A-5. Bobbin Coil Amplitude of ODSCC at TSP
Improper Identification of Full Flaw Segment.



DEG	%	DEG	%	DEG	%	DEG	%
0	0	45	93	90	56	135	0
1	3	46	93	91	54	136	0
2	6	47	92	92	53	137	0
3	9	48	92	93	52	138	0
4	12	49	91	94	51	139	0
5	15	50	90	95	50	140	0
6	18	51	90	96	48	141	0
7	21	52	89	97	47	142	0
8	24	53	88	98	46	143	0
9	27	54	88	99	45	144	0
10	30	55	87	100	43	145	0
11	33	56	86	101	42	146	0
12	36	57	86	102	41	147	0
13	39	58	85	103	39	148	0
14	42	59	84	104	38	149	0
15	45	60	83	105	37	150	0
16	48	61	83	106	35	151	0
17	52	62	82	107	34	152	0
18	55	63	81	108	32	153	0
19	58	64	80	109	31	154	0
20	61	65	79	110	29	155	0
21	64	66	79	111	28	156	0
22	67	67	78	112	26	157	0
23	70	68	77	113	25	158	0
24	73	69	76	114	23	159	0
25	76	70	75	115	22	160	0
26	79	71	74	116	20	161	0
27	82	72	74	117	18	162	0
28	85	73	73	118	17	163	0
29	88	74	72	119	15	164	0
30	91	75	71	120	13	165	0
31	94	76	70	121	12	166	0
32	97	77	69	122	10	167	0
33	100	78	68	123	8	168	0
34	99	79	67	124	6	169	0
35	99	80	66	125	4	170	0
36	98	81	65	126	2	171	0
37	98	82	64	127	1	172	0
38	97	83	63	128	0	173	0
39	97	84	62	129	0	174	0
40	96	85	61	130	0	175	0
41	96	86	60	131	0	176	0
42	95	87	59	132	0	177	0
43	95	88	58	133	0	178	0
44	94	89	57	134	0	179	0

Figure A-6. Bobbin Coil Calibration Curve for 400/100 Mix.

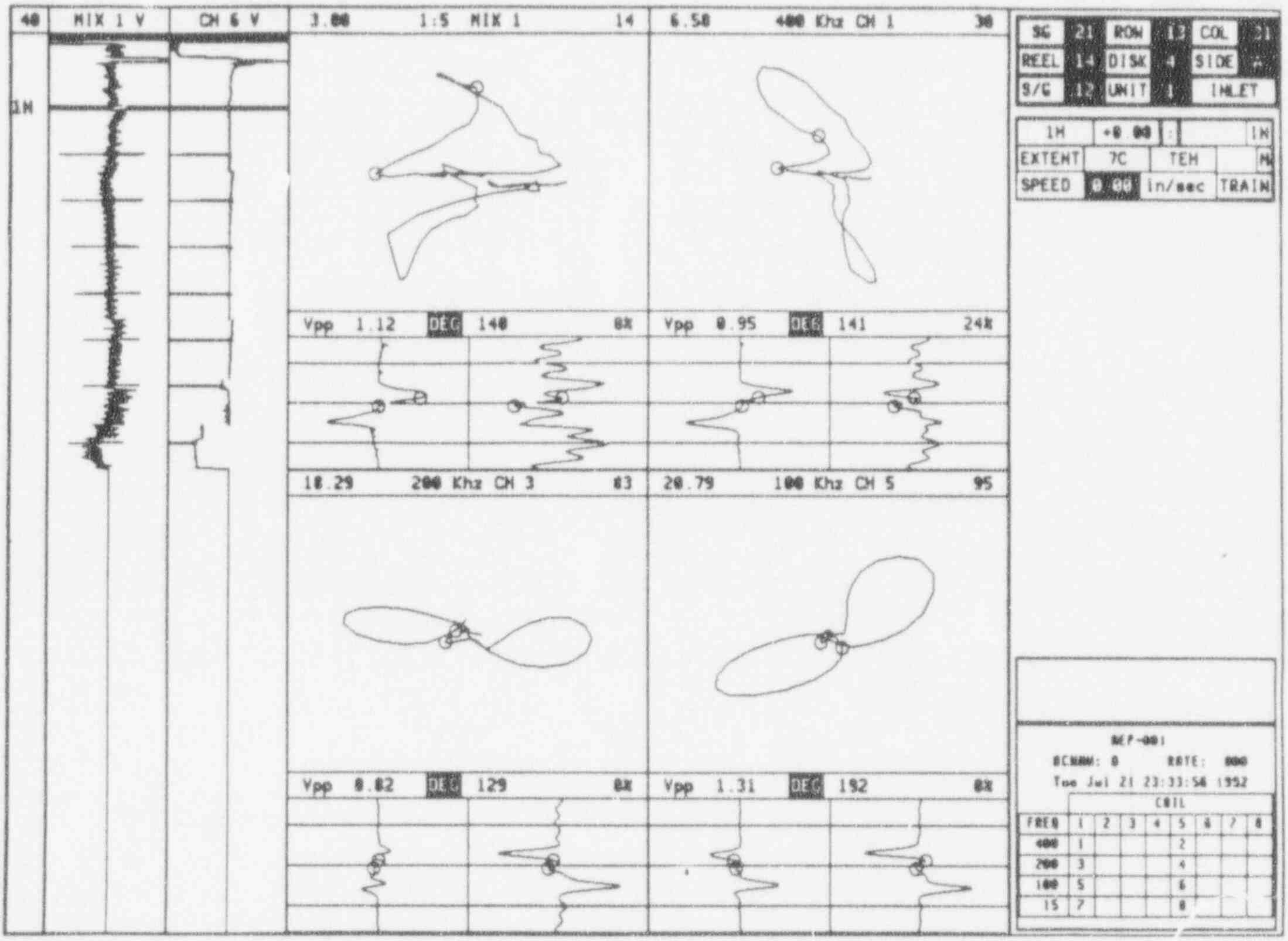


Figure A-7. O.D. Origin Signal With Phase Angle Greater Than 0% Intercept on Calibration Curve.

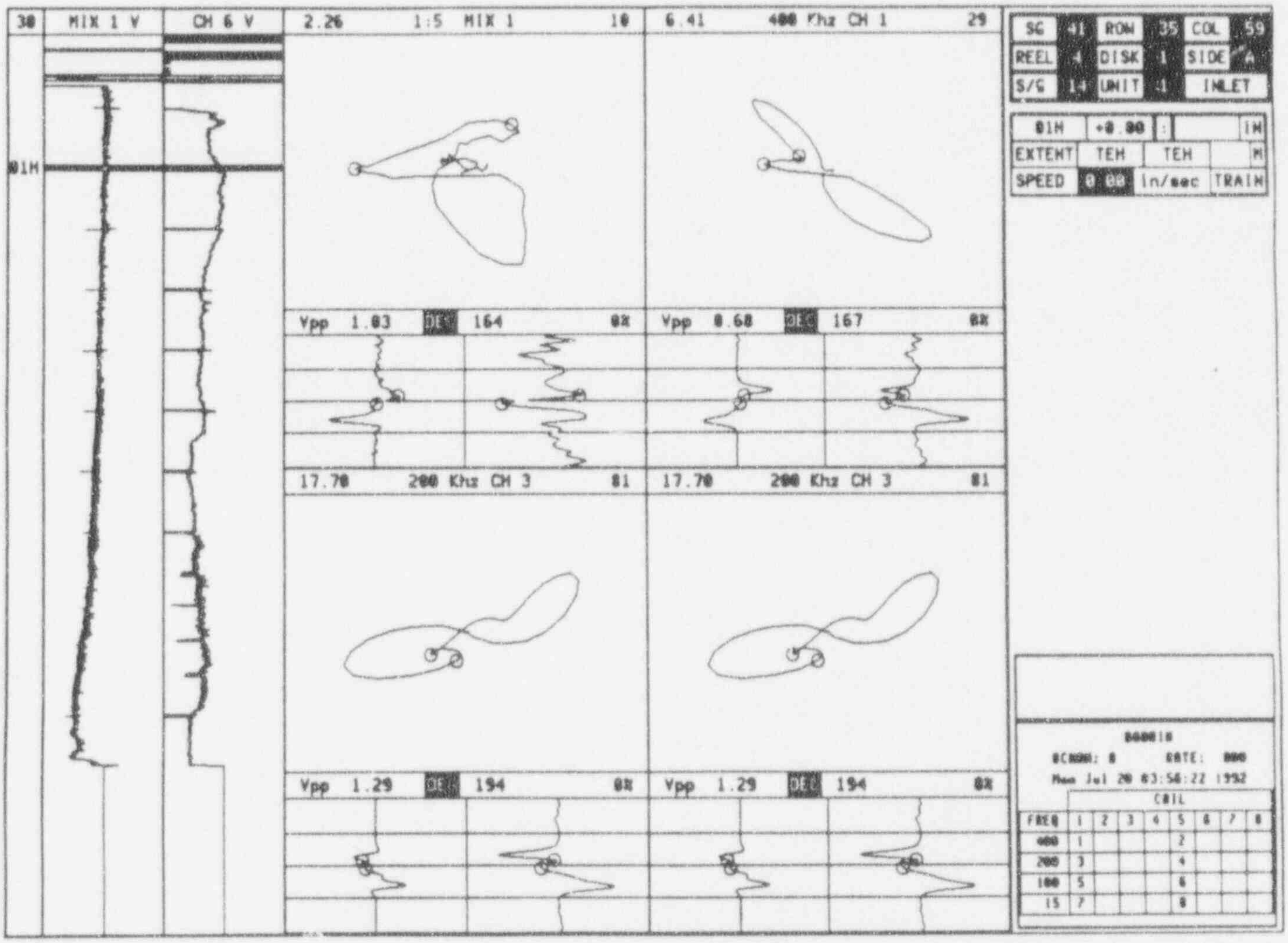


Figure A-8. O.D. Origin Signal With Phase Angle Greater Than 0% Intercept on Calibration Curve.

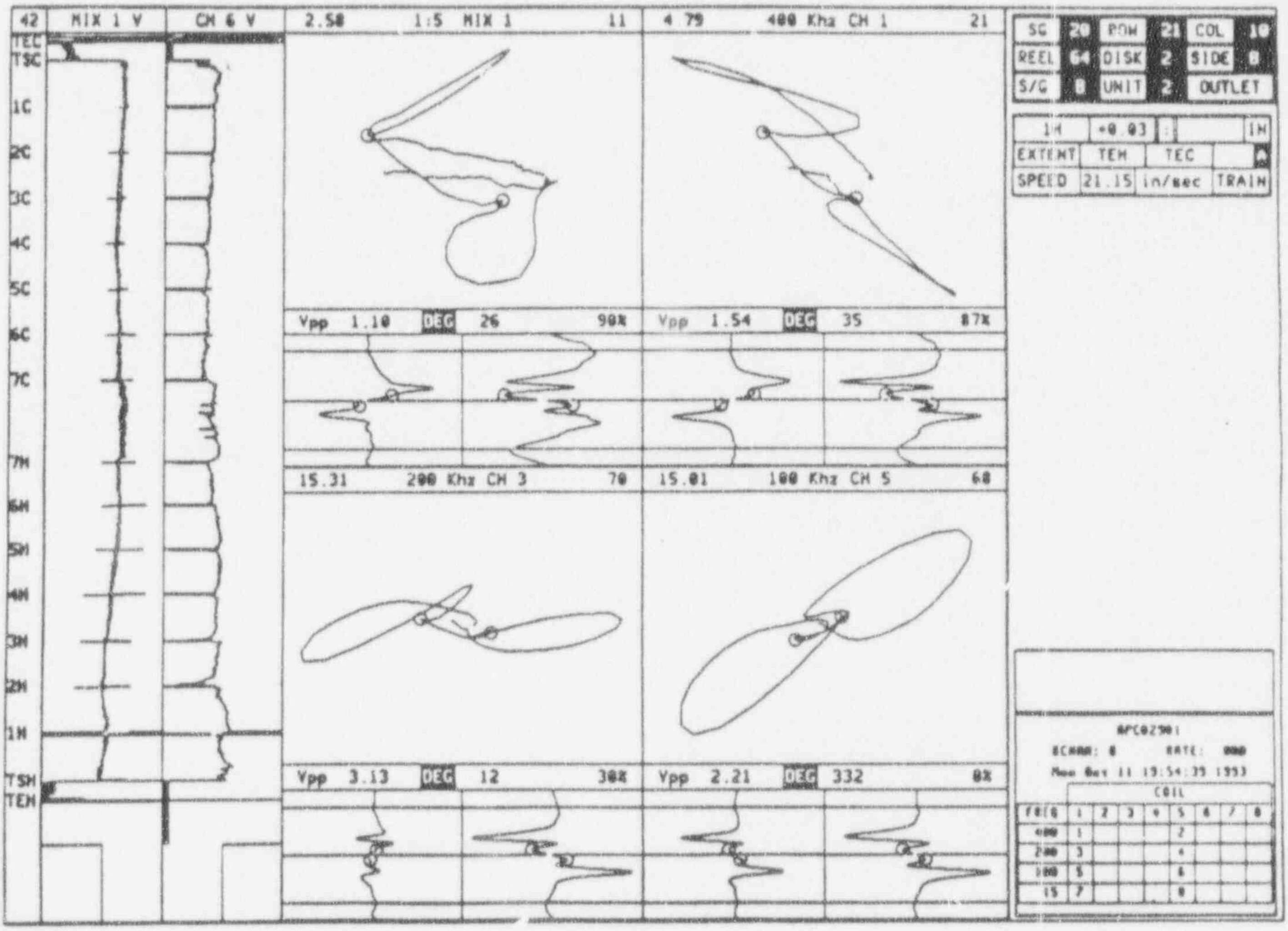


Figure A-9. I.D. Phase Signals in Bobbin 400/100 Mix.

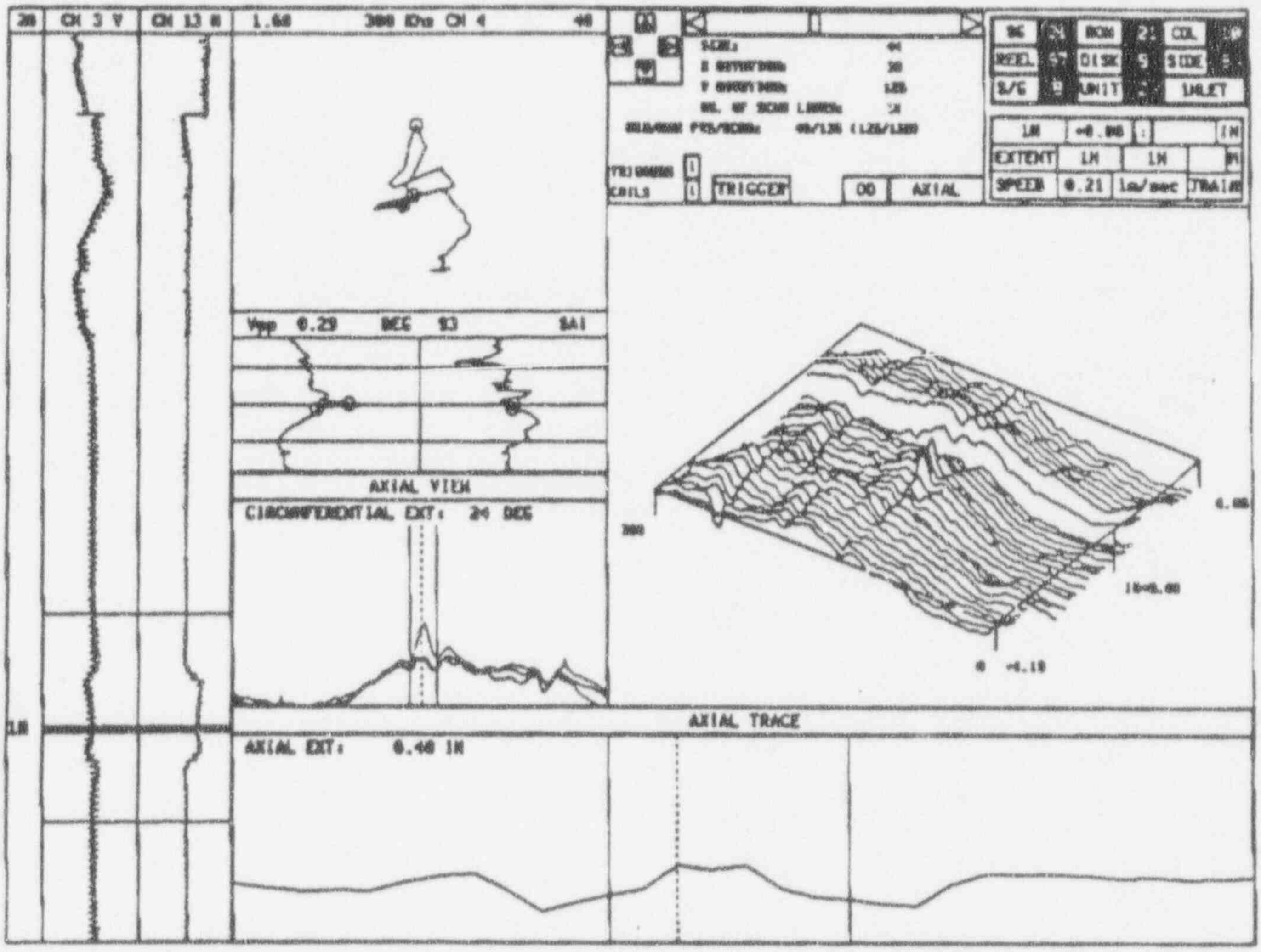


Figure A-10. O.D. Phase Signal in RPC Confirmation.

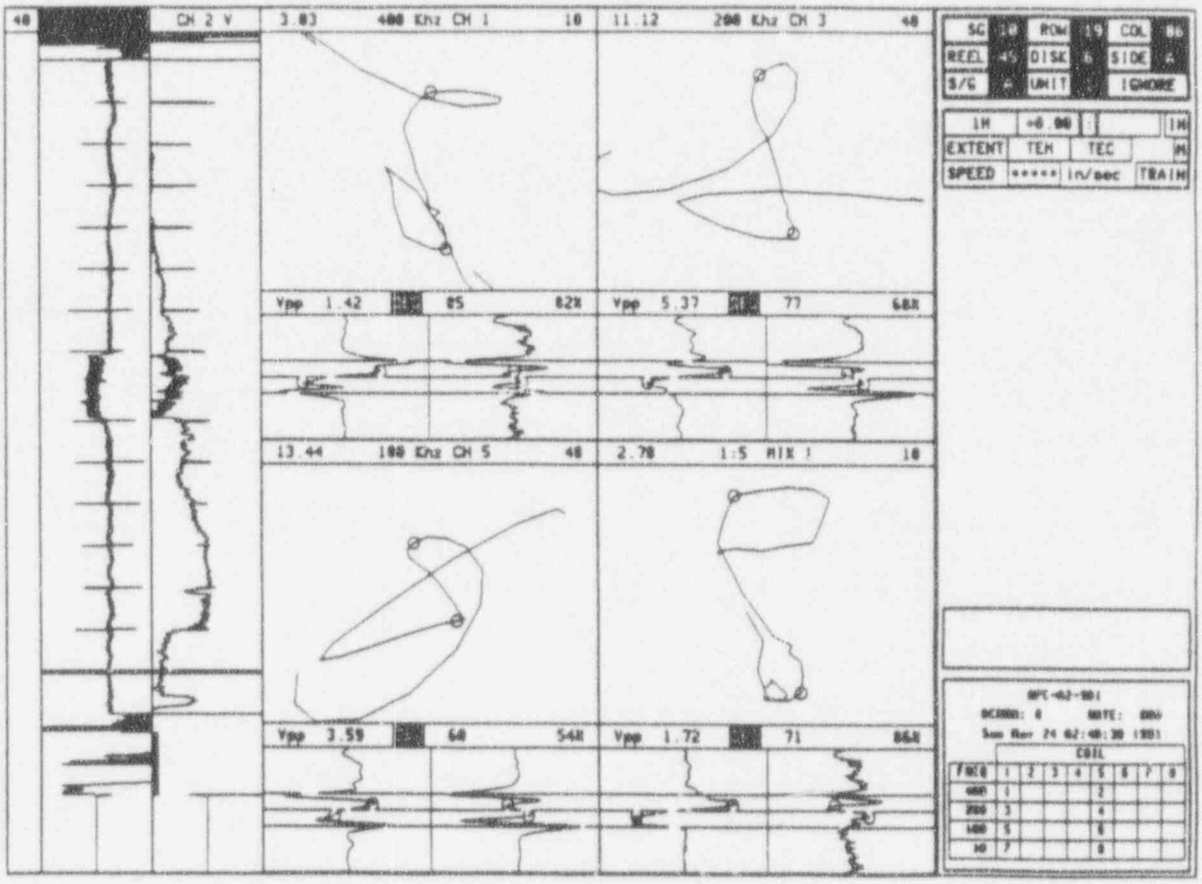


Figure A-11. Placement of Dots Marking Lissajous Traces for R19C86 - Analyst 1.

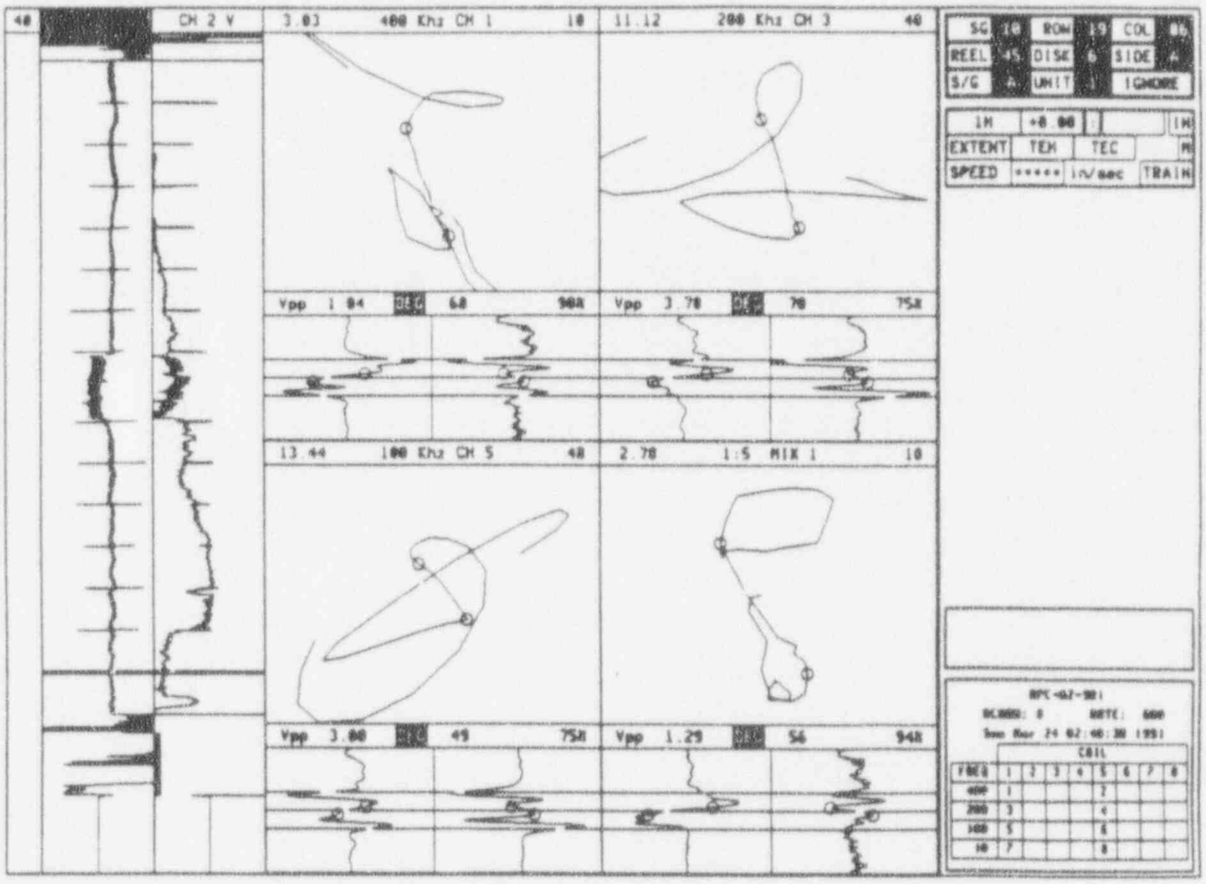


Figure A-12. Placement of Dots Marking Lissajous Traces for R19C86 - Analyst 2.

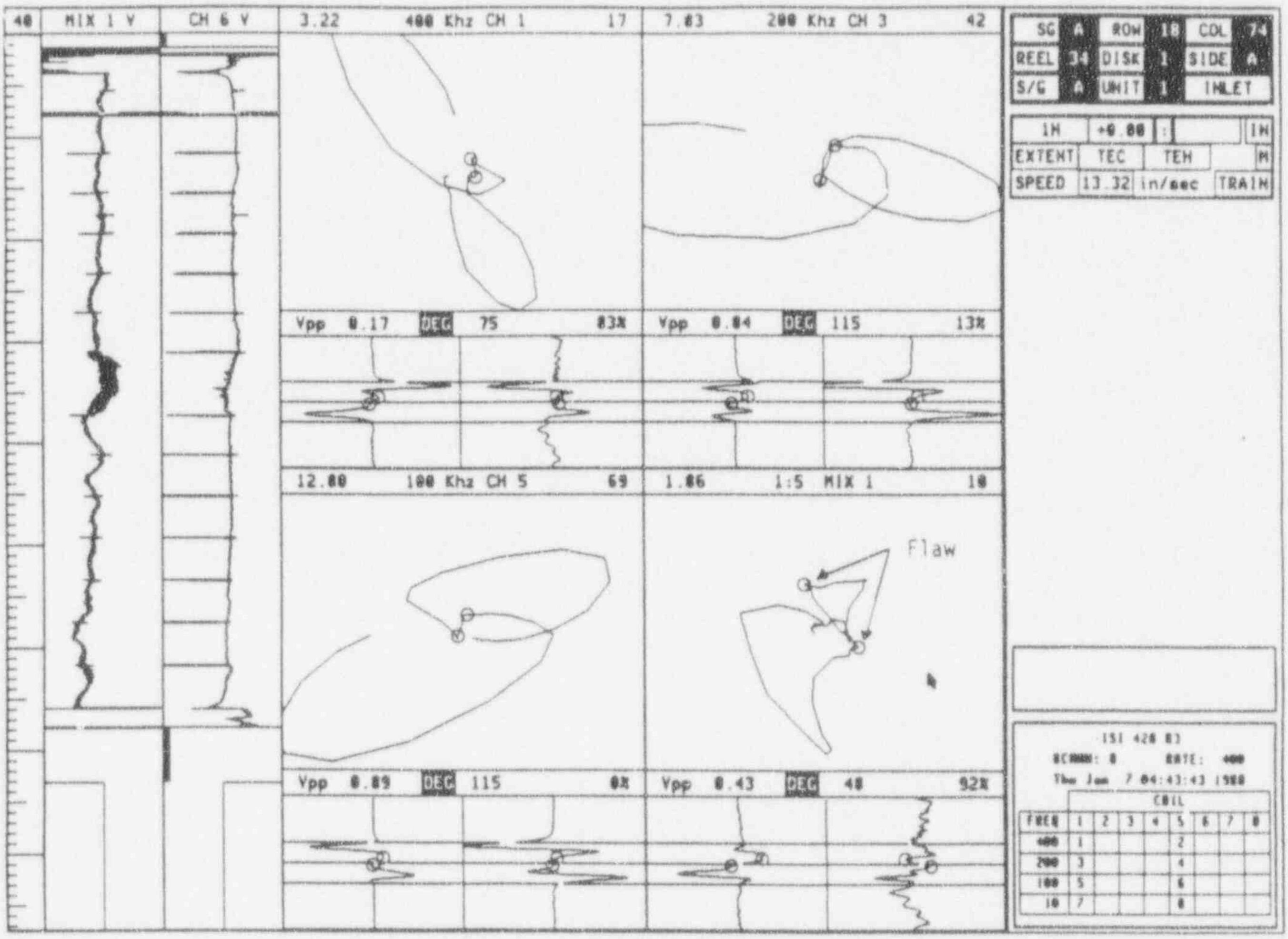


Figure A-13. Bobbin Coil Amplitude Analysis of ODSCC at TSP.

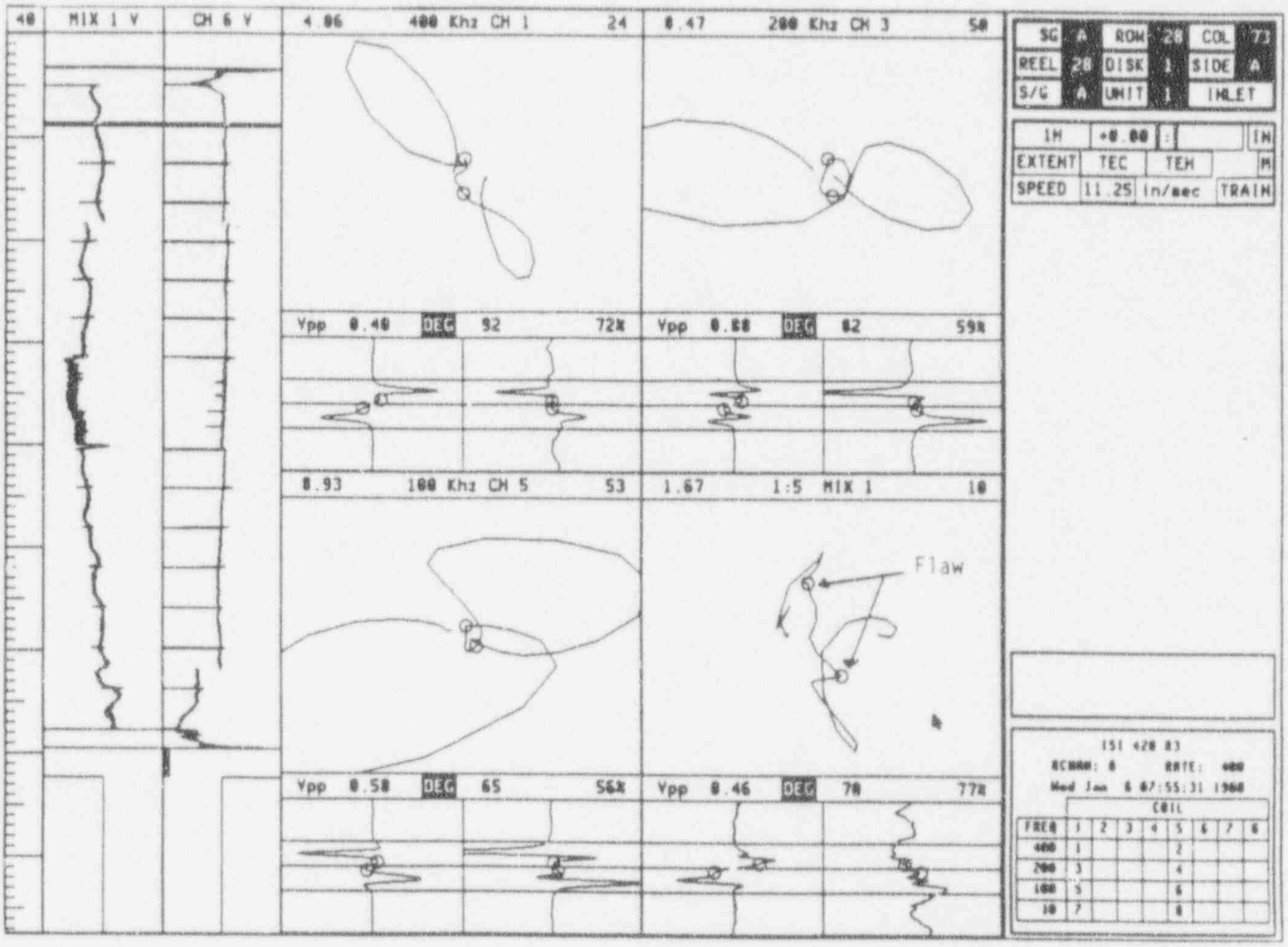


Figure A-14. Bobbin Coil Amplitude Analysis of ODSCC at TSP.

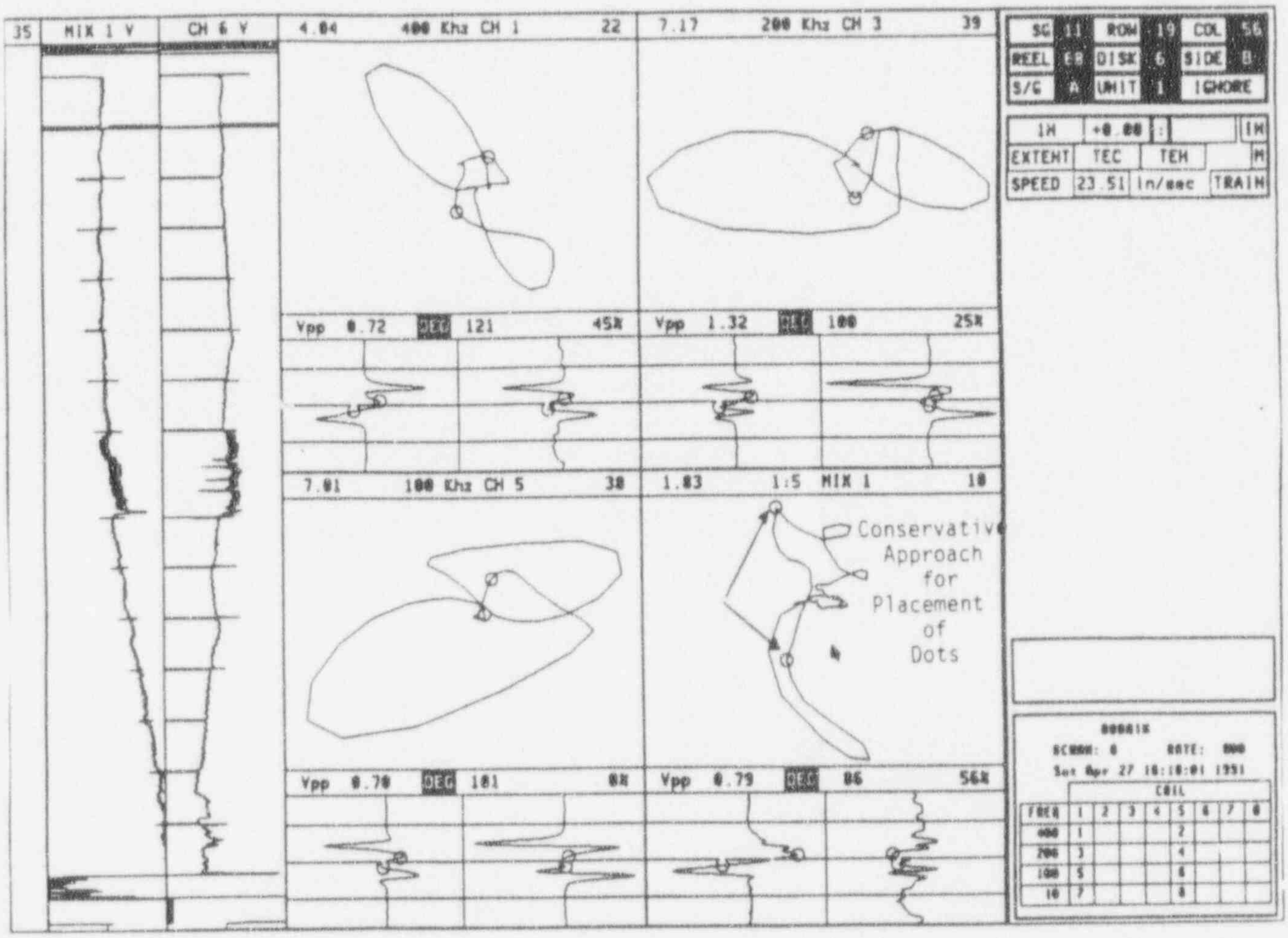


Figure A-15. Bobbin Coil Amplitude Analysis of ODSCC at TSP.

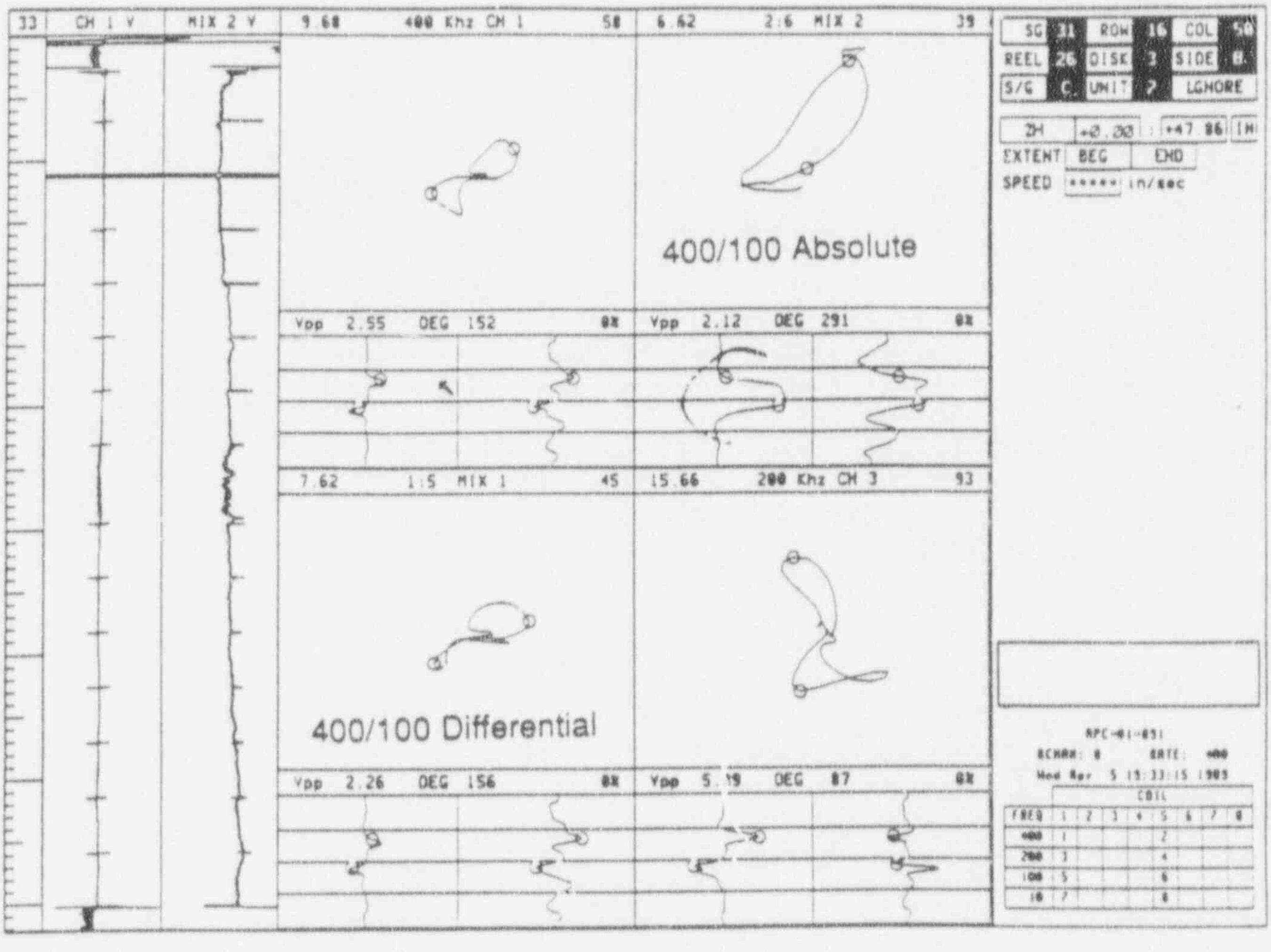


Figure A-16. Example of Bobbin Coil Field Data From Farley-2: Absolute Mix With No ODSCC.

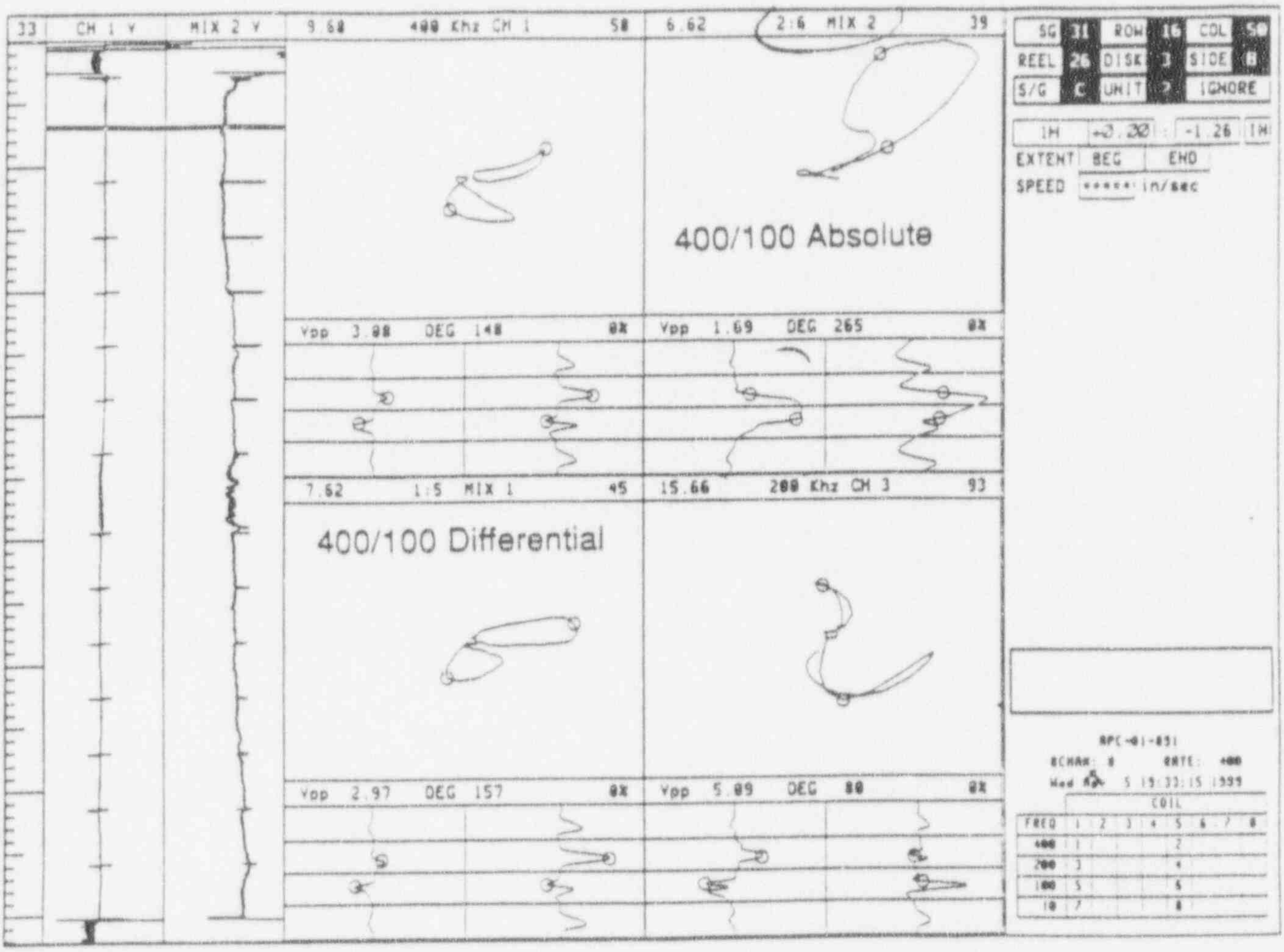


Figure A-17. Example of Bobbin Coil Field Data From Farley-2: Absolute Mix With No ODSCC.

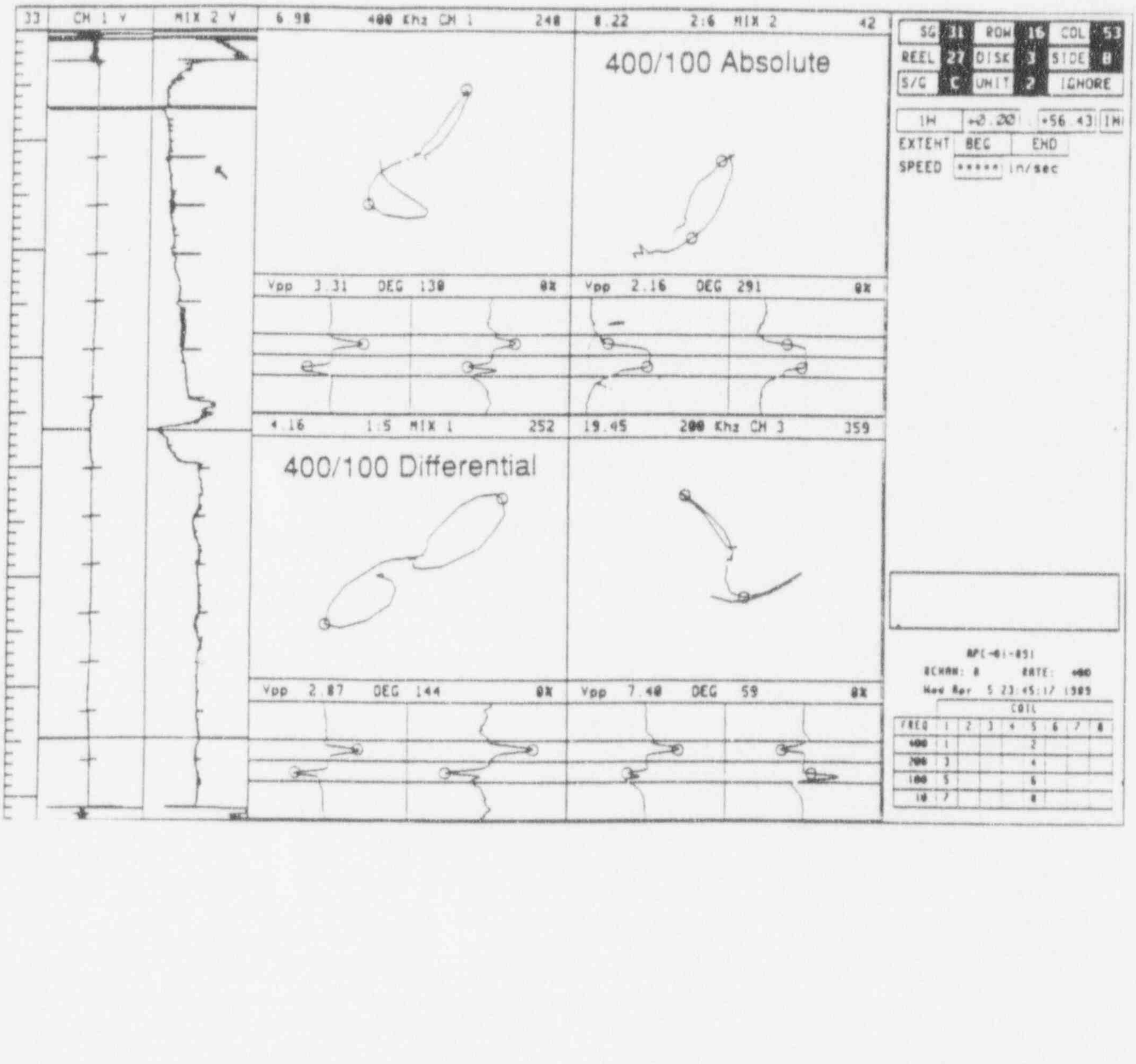


Figure A-18. Example of Bobbin Coil Field Data From Farley-2: Absolute Mix With No ODSCC.

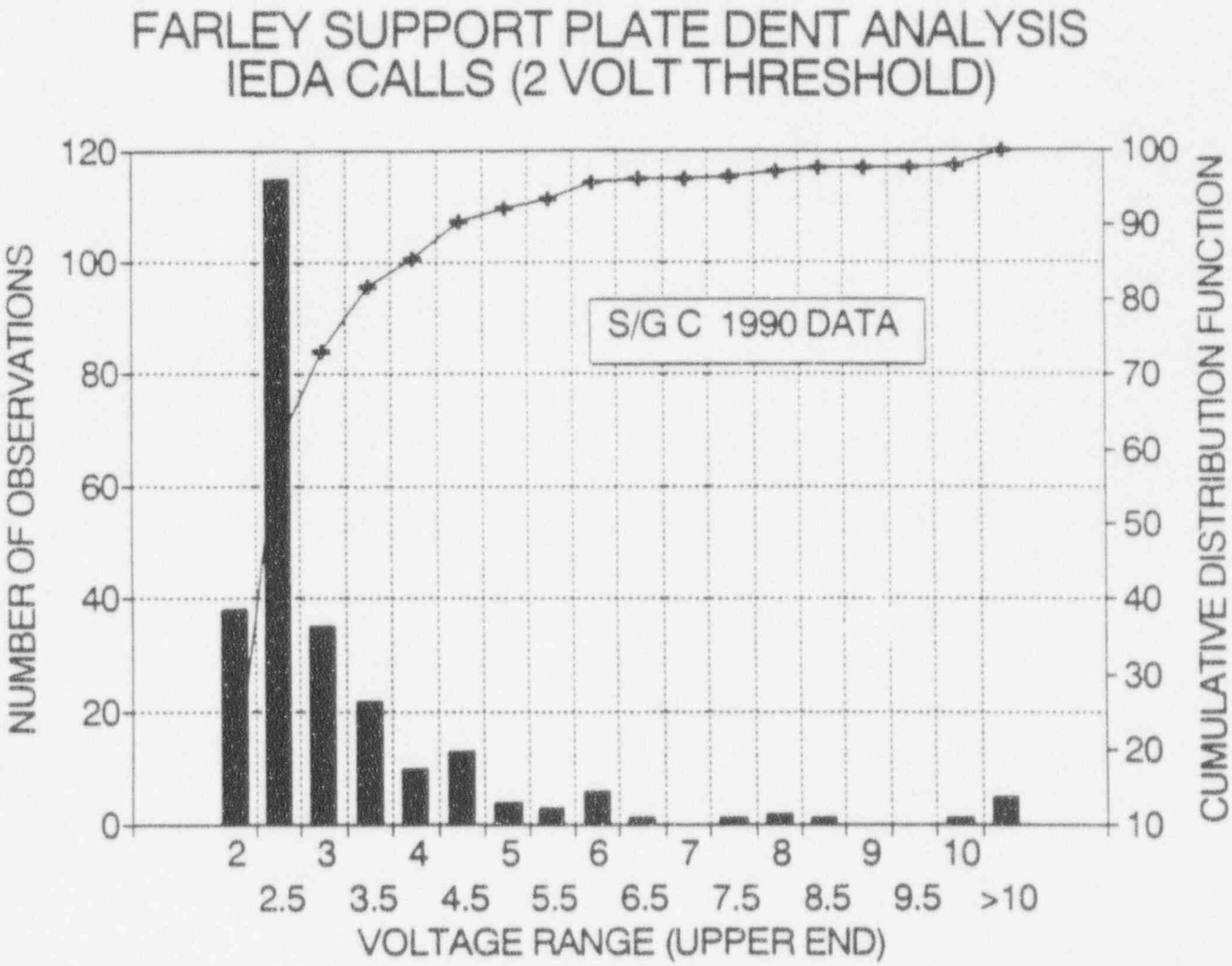


Figure A-19. Farley Unit 1, SG "C" Tube Suppo Plate Dent Size Distribution.

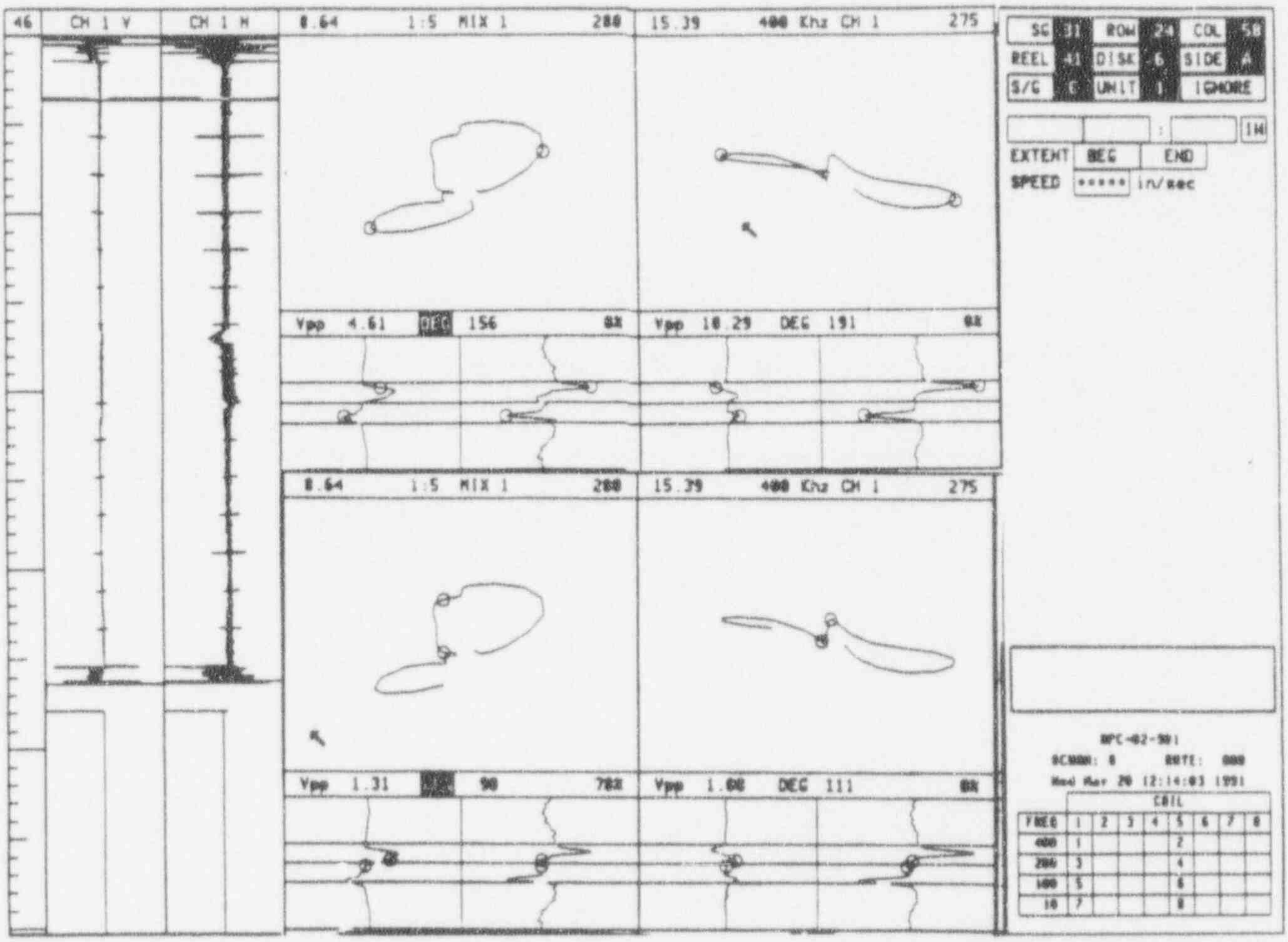


Figure A-20. Example of Bobbin Coil Field Data - Flaw Signals for ODSCC at Dented TSP Intersection.

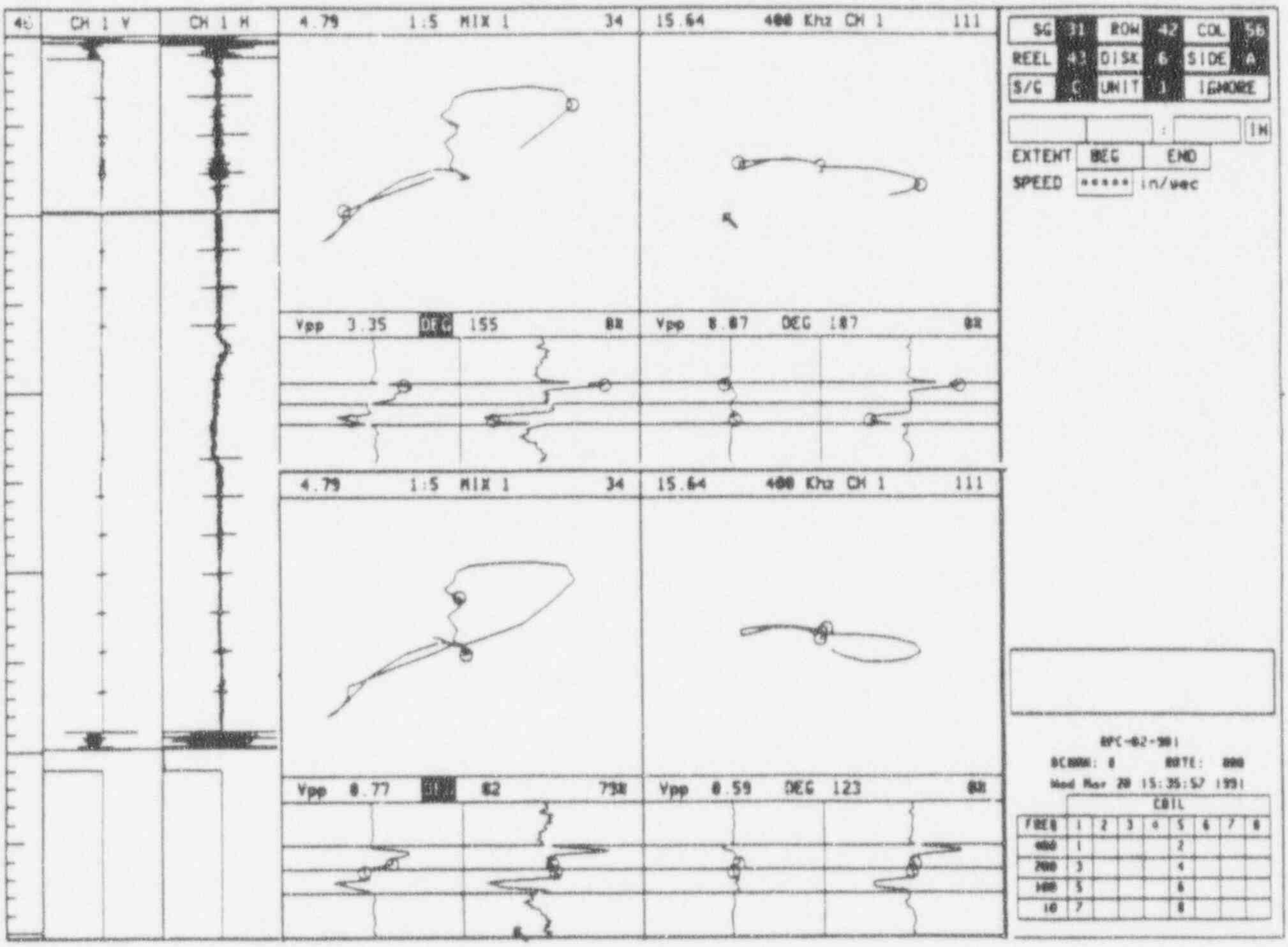


Figure A-21. Example of Bobbin Coil Field Data - Flaw Signals for ODSCC at Dented TSP Intersection.

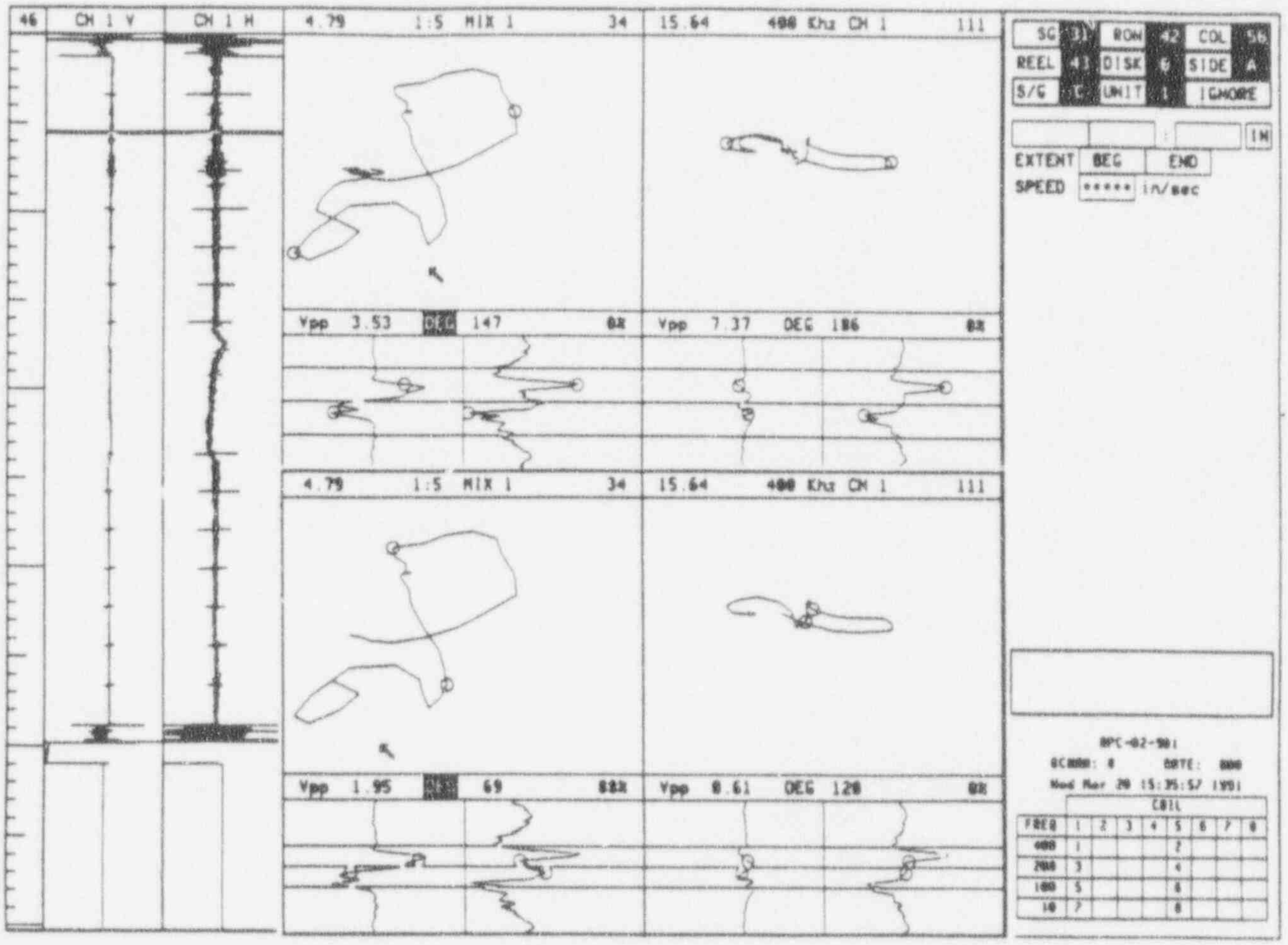


Figure A-22. Example of Bobbin Coil Field Data - Flaw Signals for ODSCC at Dented TSP Intersection.

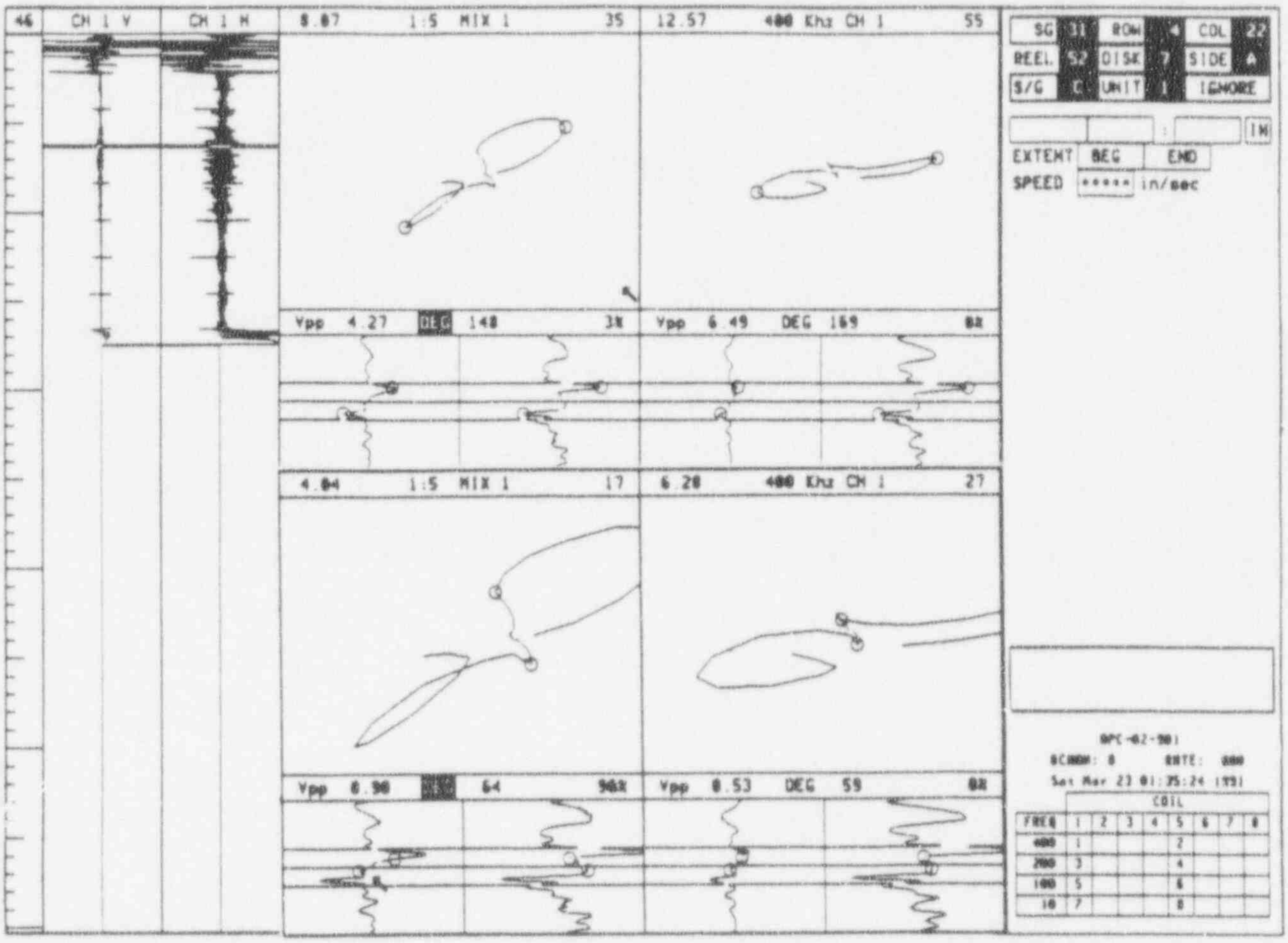


Figure A-23. Example of Bobbin Coil Field Data - Flaw Signals for ODSCC at Dented TSP Intersection.

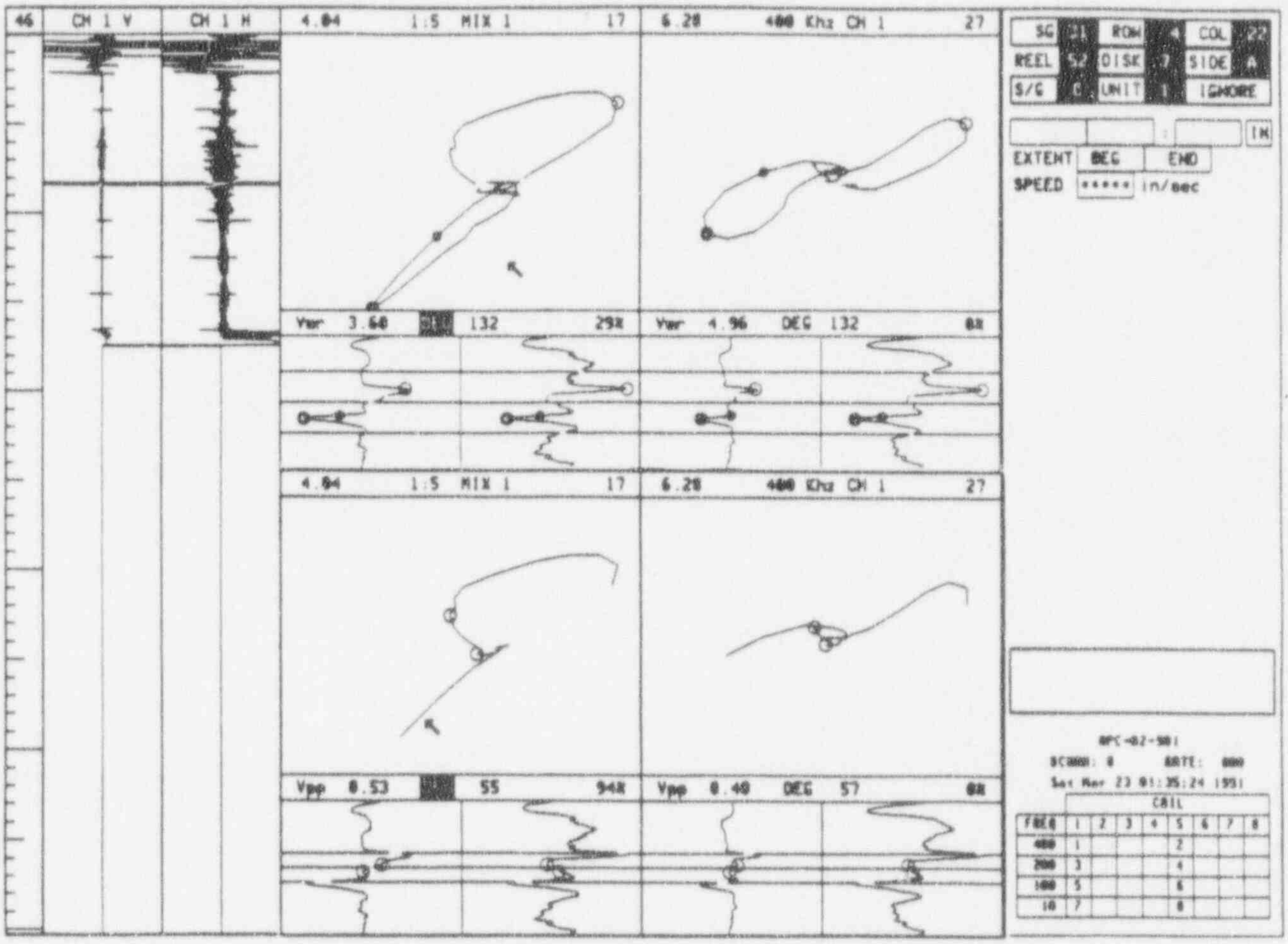


Figure A-24. Example of Bobbin Coil Field Data - Flaw Signals for ODSCC at Dented TSP Intersection.

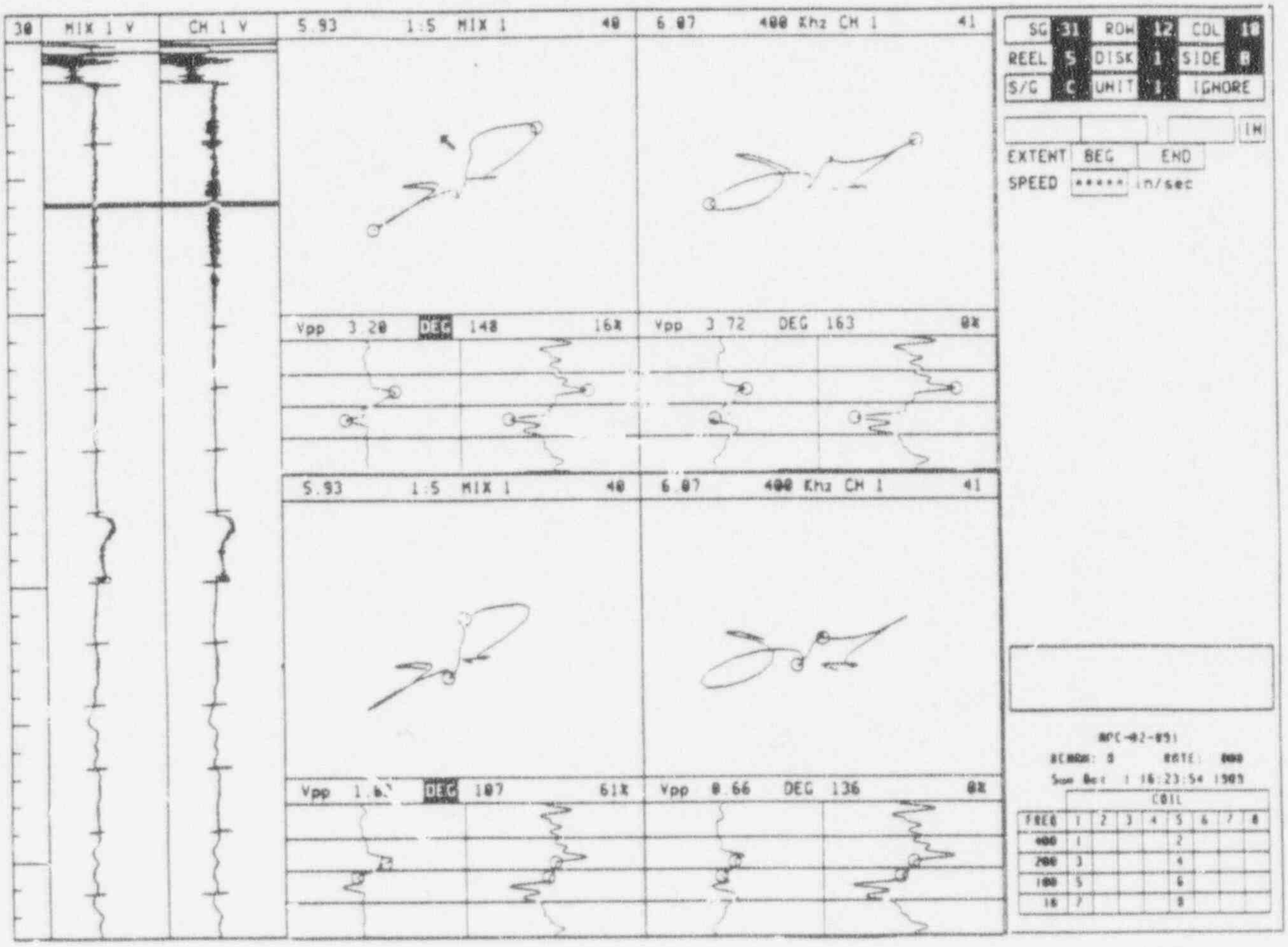


Figure A-25. Example of Bobbin Coil Field Data - Flaw Signals for ODSCC at Dented TSP Intersection.

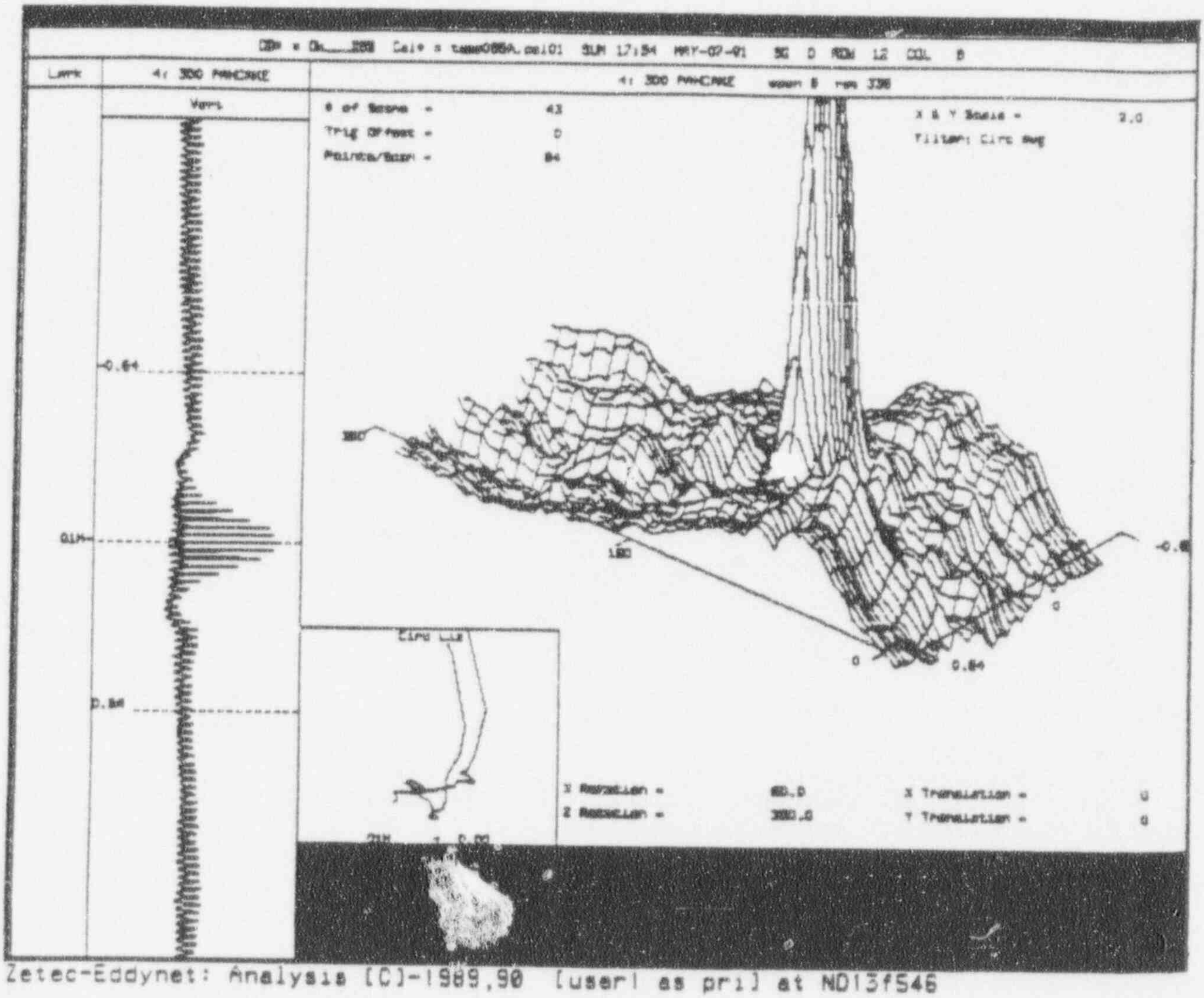


Figure A-26. Example of Axial ODSCC Indication at TSP 1.

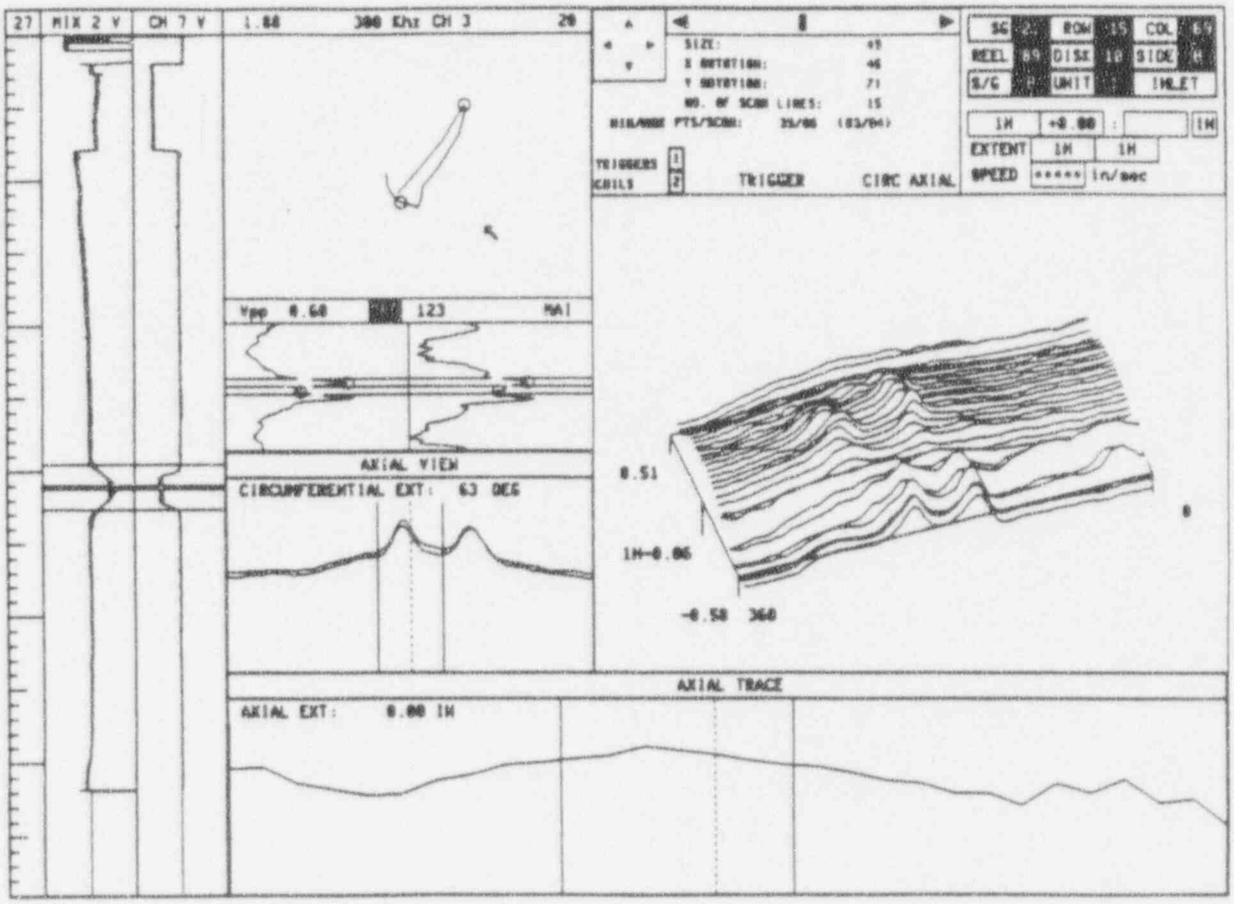


Figure A-27. Axial ODSCC Indication at TSP - Farley Unit 1.

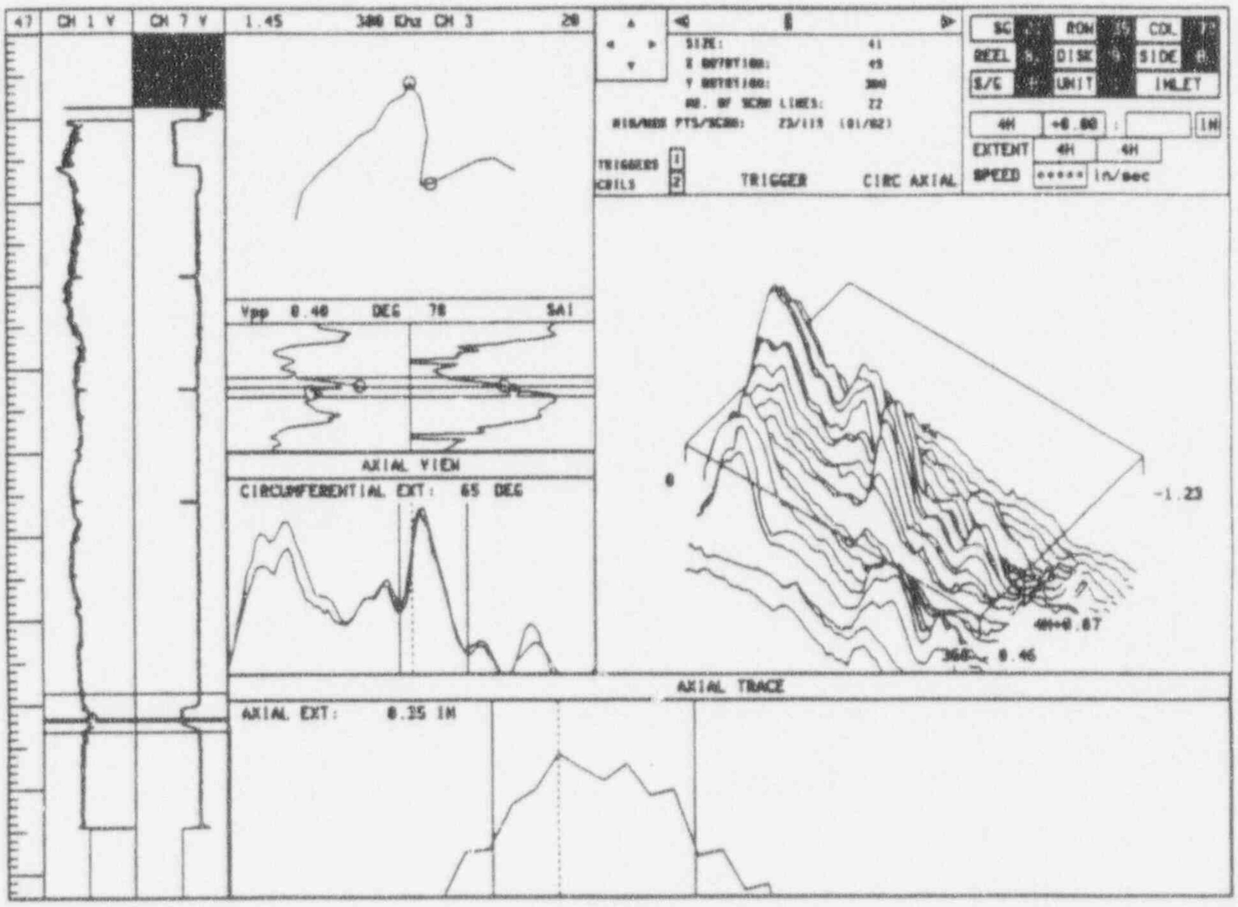


Figure A-28. Axial ODSCC Indications (MAI) at TSP - Farley Unit 1.

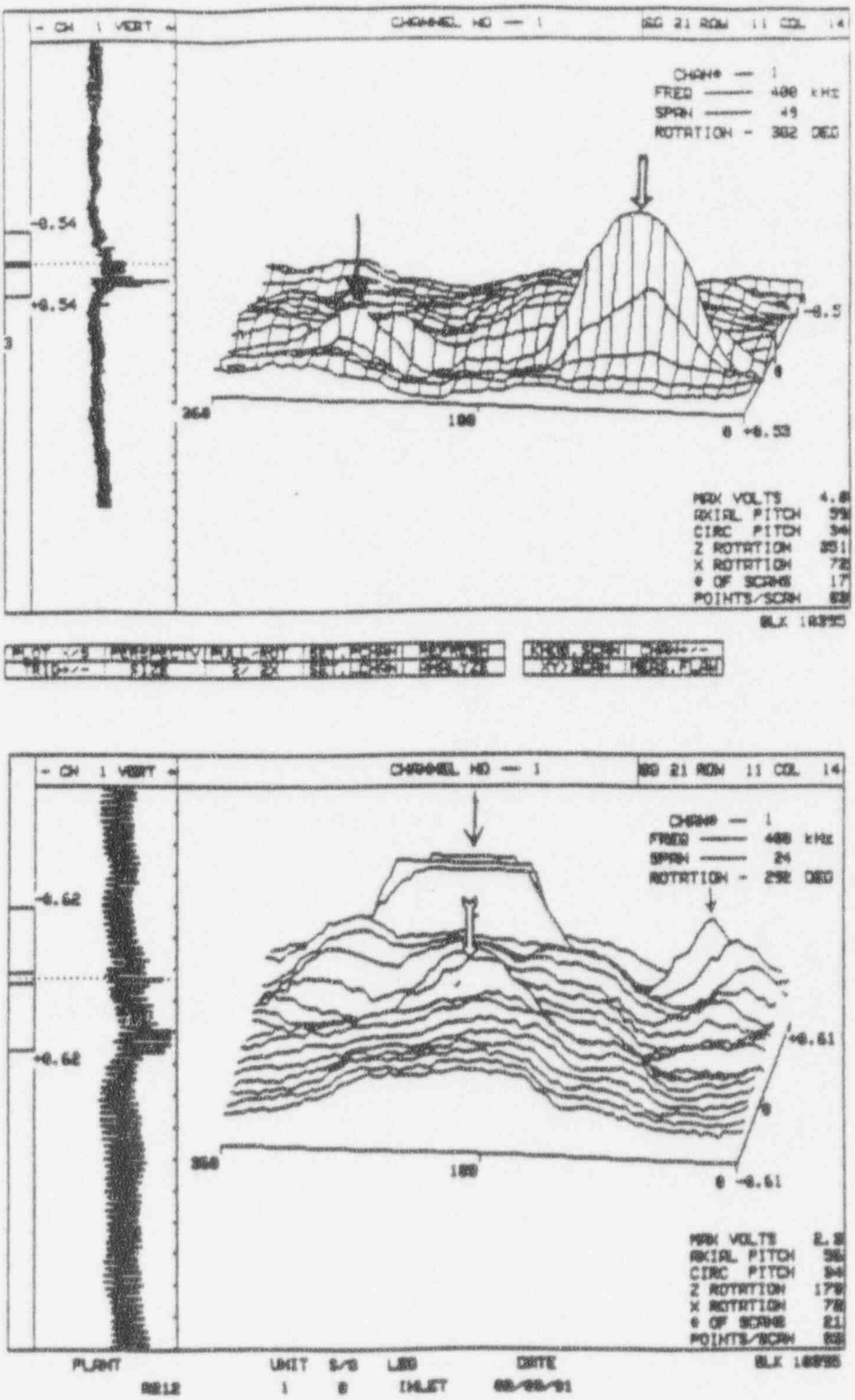
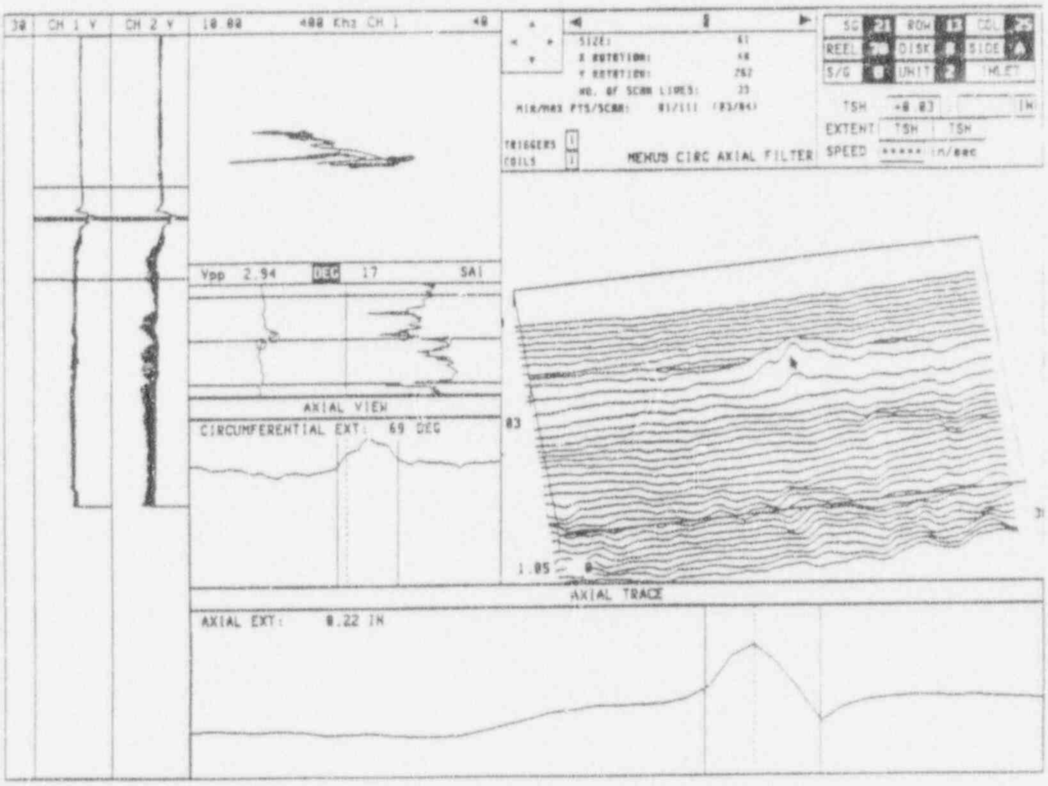
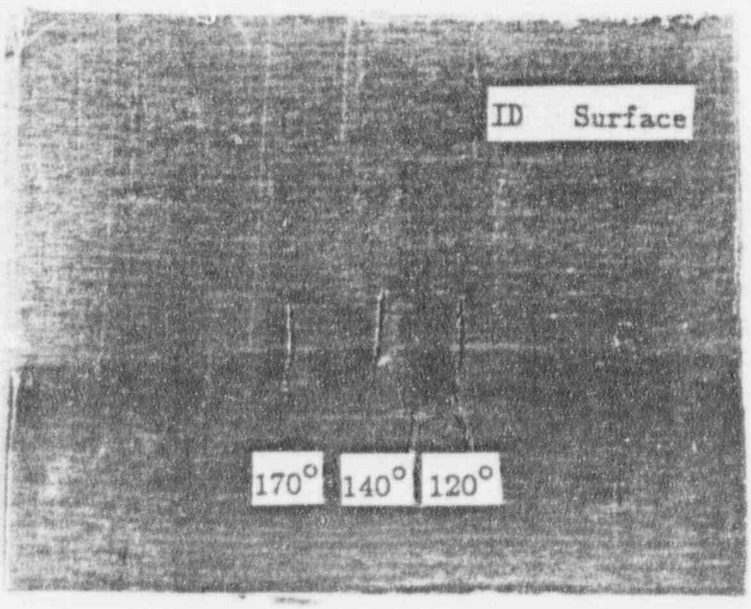


Figure A-29. Circumferential ODSCC Indications at Support Plates.



Top



Mag. 3X

Figure A-30. Farley-2 RPC and Destructive Exam Results for Closely Spaced Axial Cracks.

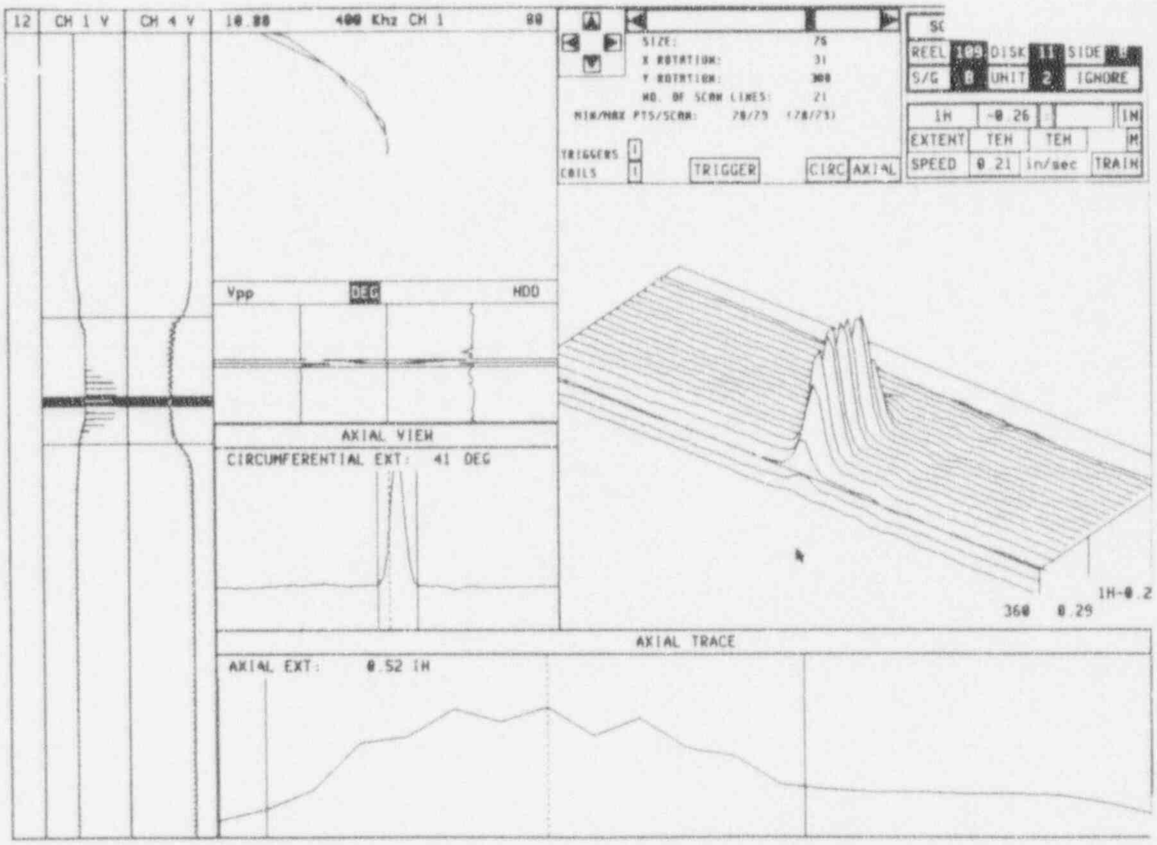


Figure A-31. Slope Intercept Measurement of Crack Length.

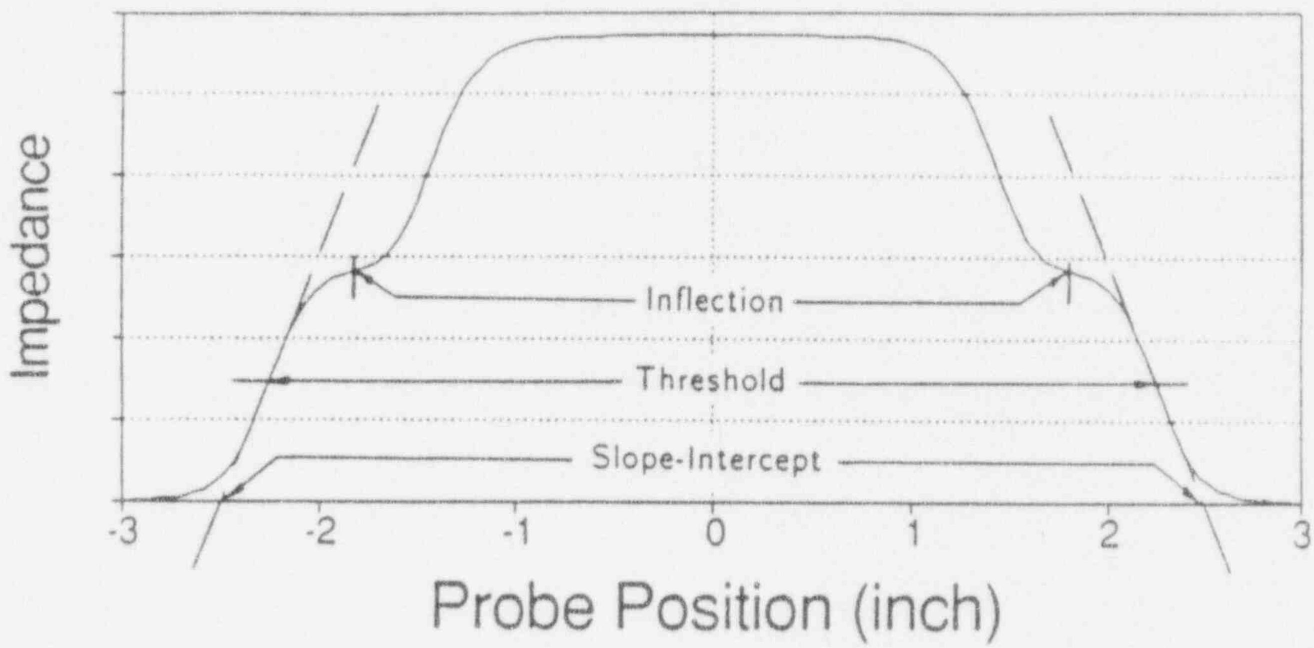


Figure A-32. Techniques for Measuring Crack Lengths From Eddy Current.

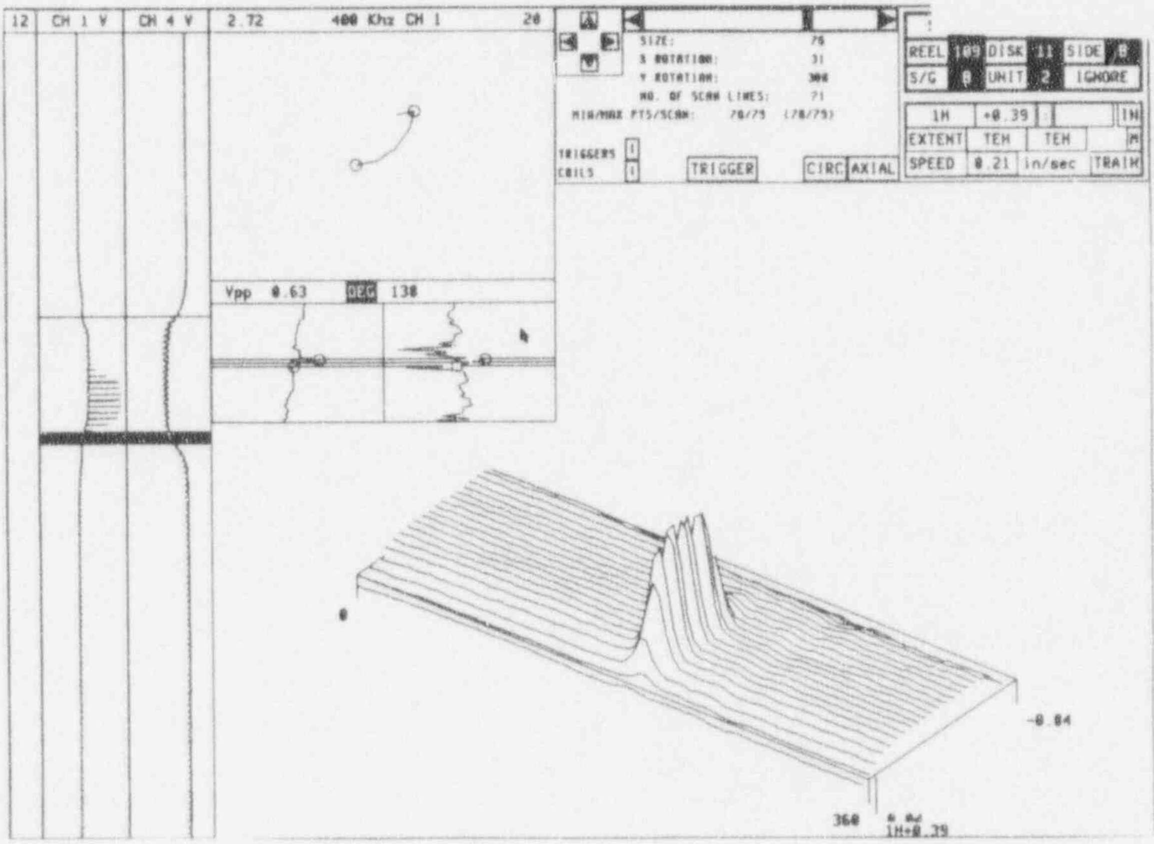


Figure A-33. First Scan Line Flaw Limit.

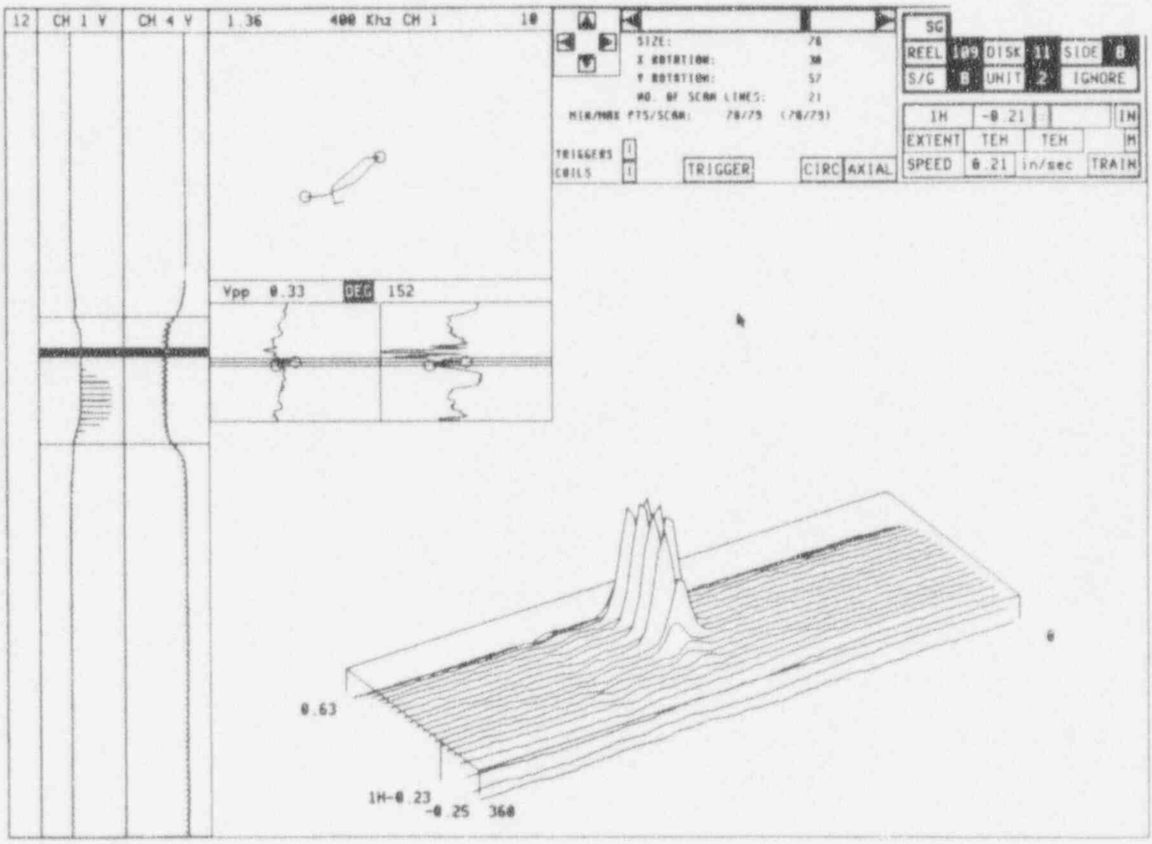


Figure A-34. Last Scan Line Flaw Limit.