Review of Tube R2C5 in Steam

Generator 24
Phase settings between 1997 and 2000

In 1997 the phase rotation for the eddy-current

X/4

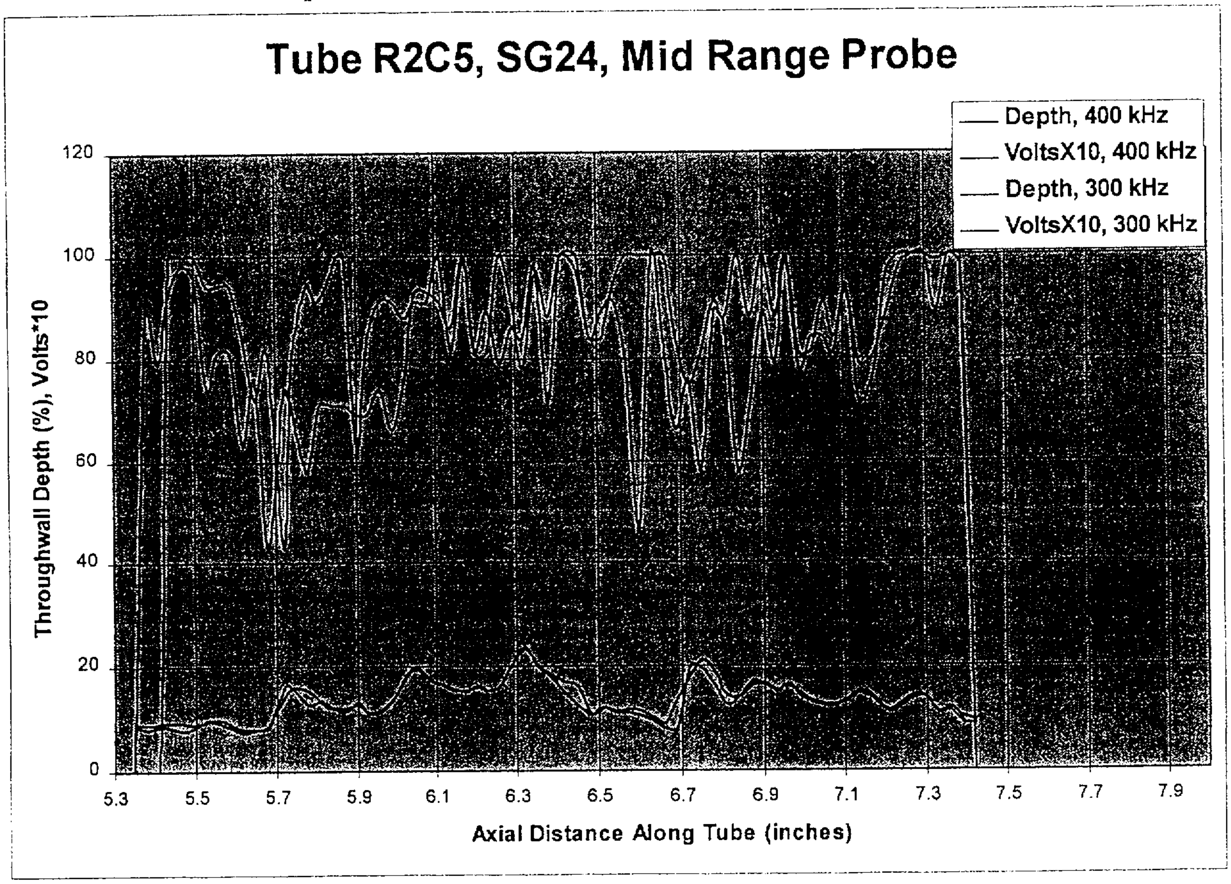
calibration was set too low, resulting in a decrease in the vertical signal that the analyst uses for screening for defects. In Figure 1 we show the c-scan plot with the phase set too low. In Figure 2 we show the phase setting that is being used for the current inspection. The indication, which is riding on a noise ridge, is easier to see. With proper training the analyst would be more likely to discover the indication with this phase setting. In Figure 3 we show the Lissajous of the indication that the arrow is pointed to.

The vertical signal with the correct phase setting changes from 0.76-volts to 1.05-volts, giving the analyst an increased chance to notice the defect. When the analyst notices the defect, he will then click on it and make a reading from the lissajous screen. The shape of the indication clearly identifies it as a crack in both Figures 3 and 4. It is slightly easier to spot in Figure 2 than it is in figure 1, due to the increased vertical amplitude. The phase setting of Figure 1 is 7 degrees lower than that of Figure 2. With the new, high-frequency probe the noise is considerably decreased, and rotated horizontal, while the signal is increased. This results in much improved detectability for these defects.

The defect signal sits on a noise ridge that runs the length of the tube. This noise ridge is about 1-volt in amplitude and measures as a deep id defect, on the order of 70 to 100% deep. This ridge makes both the detection and sizing of this defect more difficult. In Figure 5 we show the lissajous of the noise ridge. The signal-to-noise is slightly better for the 400 kHz frequency than the 300 kHz.

There is a signal on the 10 kHz channel that follows the defect. It is not known why the signal is visible at this frequency, although it may be due to a slight ferromagnetism of the crack. In Figure 6 we show the c-scan of the signal that has the same outlines as the crack.
This scan also has signal-to-noise problems. In some cases the analyst will remove any indication from the defective tubing list if a signal such as this is present.

The indication has been profiled for



both frequencies, as is shown in Figure 7. The 400kHz profile is probably slightly more accurate than the 300 kHz profile. Neither is very accurate, and until the defect voltage increases above 1.2-volts, there is considerable error. This can be contrasted to the 0.4-volt threshold for the high-frequency probe. No attempt has been made to adjust these profiles for the end effects of the probe.

Signal Filtering
The Zetec software (and I believe also the Anser software) has the ability to subtract an average signal or a single line signal from both the axial and circumferential c-scan plots. The main use if these "filters" is for cases like this were you need to separate a defect from other naturally occurring signals with relatively constant shapes, such as tube supports or these ridges. A number of different processing methods are referred to as filters, including this type of simple subtraction filter and frequency filters. Westinghouse discourages the use of filters in general since they throw away some of the signal that may contain a defect. The analyst guidelines states that the analyst does have the option of using filters, but it is not mandatory. In Figure 8 we show a C-scan of the R2C5 using the circumferential line filter. We are subtracting the signal form a single circumferential line set at the location of the arrow. The defect is easier to see at this location. The signal from the ridges cancels out near the location that we set the line filter, but, due to the variation of the axial ridges with distance along the tube, it reappears a short distance away. However, the defect signal is displayed in a form easier to recognize. This scan can be compared to the scan in Figure 2 with the line filter off. This method can be used as a tool to help the analyst, but it also does not do as good a job of eliminating the noise signals as the high-frequency probe. It is hard to use the filters and do a profile of the tube since the filters turns off when the next line scan button is pushed.

Probe skipping has been mentioned as a possible factor in this signal being missed. A review of the data indicates that this was not a significant factor in any of the defects in 1997 being missed.

Conclusions
The main reasons for this defect being missed was due to poor analyst performance and the use of a technique that was designed for od defects being used for id defects. The reason for the poor analyst performance is not clear because there is no documentation on the training that the analyst received in 1997. The guidelines that the analyst used in 1997 was of poor quality and difficult to read.

Review of Indian Point

On Thursday, March 9, I reviewed the eddy-current inspection at the Indian Point 2 power plant. The prior inspection, in 1997 had been done with probes and procedures designed to detect od defects, rather than the id defects that are present in the u-bends. In addition, the phase setting used by the utility, which is critical for id defect detection, was an old one specified for pancake probes, which is not adequate for the plus-point probe. The EPRI probe qualification for the plus-point used a correct setting in 1997 and uses the correct one at the present time. In reviewing the data, it was obvious that the phase setting was too low in 1997. This was one contributing factor to the indication being missed. The correct phase setting was already being used at this inspection when we visited the plant.

Among our observations was that the noise decreased as the frequency increased, and that the signal from the defect increased. This is expected for id defects, with artifacts on the od that generate noise. Simply increasing the frequency and reducing the probe size will limit the eddy-current signal on the outside of the tube while increasing the concentration of eddy-currents on the inside wall of the tube. This is the well known "skin-effect", and has been employed for years in general eddy-current testing. However, in the steam-generator tube-testing business, most of the defects and problems have been on the exterior of the tube, where they are much harder to detect.

Another observation was that the guidelines were very poor. I made a number of specific recommendations for the improvement of the guidelines. In general, most utilities have poor guidelines that do not fulfill their purpose of insuring an uniform and repeatable inspection. The utilities should spend more effort on their guidelines so the time spent training a large number of analysts is not wasted. It should be noted that most utilities have poor guidelines until NRC " suggests" upgrades. The utility has not documented the training that the analysts are given. This is particularly important in this case, since they are being trained at different times.

I made a number of specific recommendations to the utility to improve the test in three areas of the generator, the u-bends, the sludge pile region, and the tube support region. They are as follows:

Recommendations for U-bend inspection improvement, in decreasing order of importance.

1. Use a smaller, high-frequency plus-point probe. I talked with the manufacturer of the plus-point probe, and "negotiated" a 0.075-inch long probe that would work to 1 MHz. The utility had ordered this probe, had EPRI test it, and applied it to the steam-generators. The results were excellent, as will be discussed later.

2. Increase the frequency of the present midrange plus-point probe. Zetec has said that these probes can be operated as high as 500 kHz. Gary Henry of EPRI has tested the probes to 750 kHz.

3. Use a 400 kHz-100 kHz mix to reduce the effects of od noise. Both the utility and I

have checked this out and determined that more development will be needed to get any significant improvement in this. However, it allows the possibility of analyzing the data previously acquired, including the 1997 inspection. A method that utilizes the greater phase rotation with frequency for od artifacts may give the needed improvements. Also, using more frequencies may improve this type of mixing. At least a limited amount of data should be acquired in this region using the new probe, operated over a broad frequency range (300 kHz to 1 MHz). This type of mixing will require the addition of copper and ferrite to the od of the tubing calibration standard.

4. Analyze the 400 kHz data in addition to the 300 kHz data that the guidelines now require. I believe that the utility is now doing this.

5. Use the correct phase setting for the different frequencies. The utility is now doing this for the present analysis. This is also being applied at the "look-back" of the 1997 data. An increased phase setting may be required for the best analysis of the higher frequency data.

Improve the sludge pile inspection

Try the mixing techniques and additional frequencies as outlined in section 3 above. This improvement will not be as easy to achieve, nor the results as spectacular as the inspection for id defects. However, the present inspection appears to me to have a region of low-sensitivity near the top of the sludge pile region. There also may be a similar region above the tubes that have significant deposits. While we have not had a tube rupture in this region as of yet, we should be aware of the problems that the deposits are causing, and their potential for masking flaws.

Improve the support plate detection

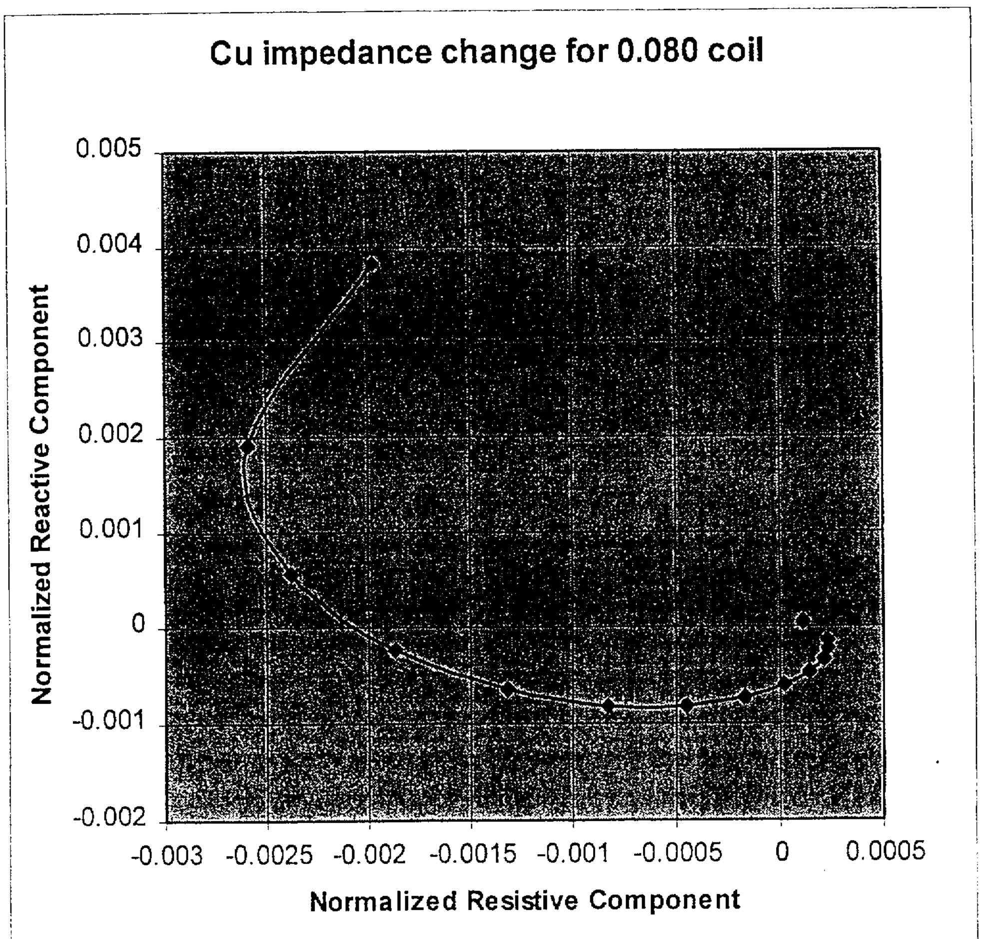
Try mixing techniques and additional frequencies as outlined in section 3 above. I do not feel that this region is as critical or as susceptible to tube rupture due to the presence of the support plates. In addition, the new smaller, high-frequency probe should do a very good job of detecting id defects at dented support plates.

Improve the Guidelines Training and Testing

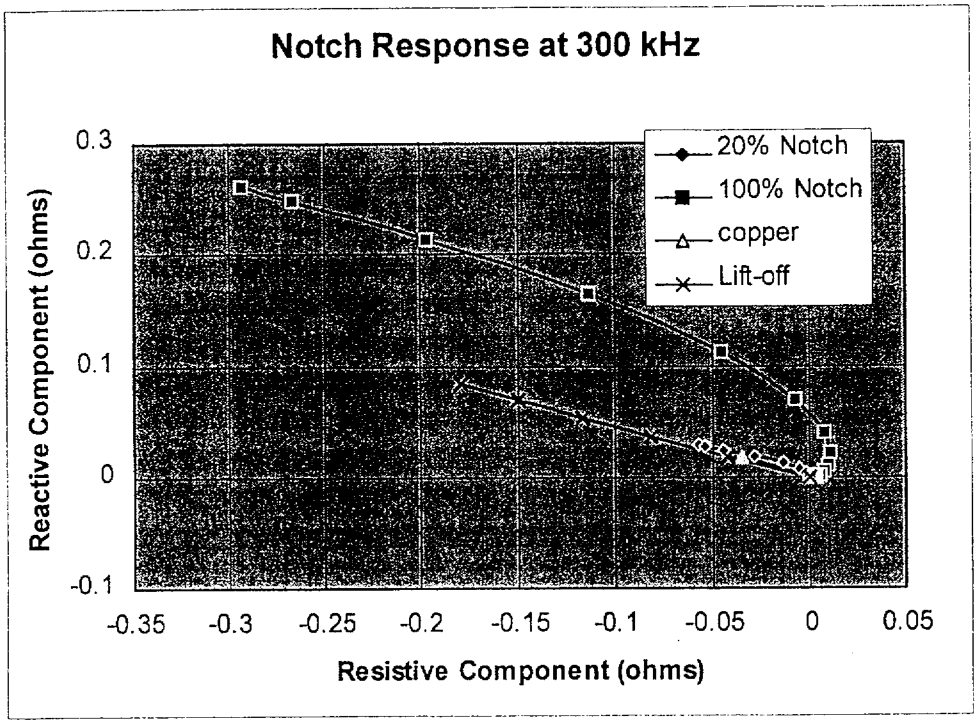
The guidelines need to be a more readable document, with figures interspersed in the text, rather than gathered at the end. The history of these generators from the eddy-current prospective is too brief. Due to the increased probability of part of the support plate falling between the tubes, loose part inspection should be emphasized. The ACTS sheets do not match the figures in the present guidelines. A written procedure is needed for the bad data rejection calls that are being made. The figure and table captions should contain all the information needed to explain them. Written documentation should be provided for the training and testing. The utility should make more of an effort to prepare good guidelines and training. This would save money in the long run. Also, the good guidelines and well documented training will allow the utility and the NRC to tell the type of inspection that was done at prior outages. The test is designed to insure that an analyst will achieve a certain probability of detecting defects in the field. During the testing, the utility does not grade off for false positive calls, so the analyst can call everything and increase his chance of passing. However, there is an analyst feedback at the end of each day. If an analyst makes a lot of false calls, which dumps extra work on the resolution analyst, he will be sent home. A method of testing the analyst under actual field conditions is needed.

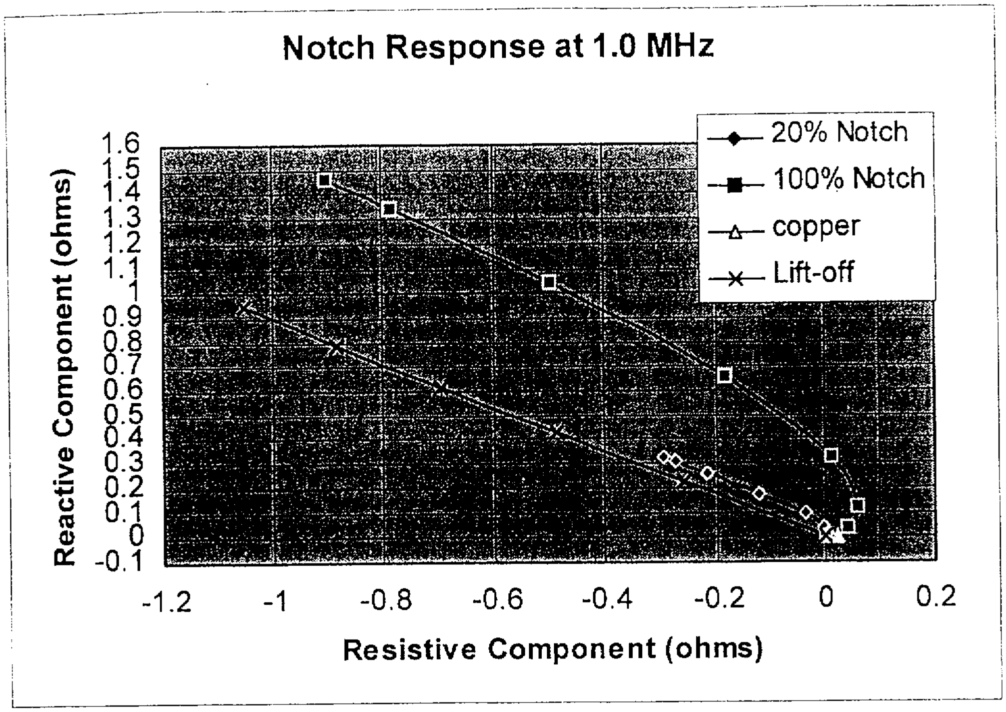
High-frequency, smaller probe development.

The high-frequency 0.075-inch probe should reduce the effects of od deposits in two different ways. The amplitude of the signal should decrease as frequency increases and the predominant phase of the noise signal should rotate. If this noise signal can be made to be horizontal with respect to the phase setting of the defect signals, then a much greater signal-to-vertical-noise ratio can be achieved.



In Figure 1 the computed the normalized impedance change for a 0.080 pancake probe between no copper and an infinite thickness of copper on the outside of the Inconel tubing is shown. The frequency is increased form 300 kHz to 2 MHz in 100 kHz steps, with a jump from 1.5 MHz to 2 MHz for the last two steps. The amplitude of the impedance change at 1.0 MHz is 17.5% of that at 300 kHz, and the phase has been shifted about 90 degrees. This "noise signal" does not give a straight vector from zero thickness to infinite thickness, but will produce a "fish-hook" shaped vector. Due to edge effects and other geometry variations, the signal can have a number of variations. However, this does give an estimate of the effect. The noise measurements show a predominate signal with smaller variations at other angles. While this gives a rough indication of what may be done, better estimates will come from combined computations and measurements. The VIC-3D program can give fairly good computations for the signals produced by notches of different depths. Notches of 20% id and 100% deep notch have been run. Provides a phase setting and a better amplitude setting for the





test and shows how the phase can be adjusted to reduce the noise. The computations for the 100% notch have not converged properly yet, but they give an approximate reading of its effect. The computations of the copper and lift-off are very accurate. In Figure 2 we show the computations for the 0.080-inch probe at 300 kHz. (The modeling has not been done for the plus-point probe, but the media effects will be somewhat similar.) Note that the phase orientation of the 20% notch, the copper coating and the lift-off signal all have about the same phase shift. ODSCC defect signals in the generator have amplitudes of about 10% of the notch amplitude, but the same phase. Therefore, as can clearly be seen, the defects are impossible to separate from the noise.

By contrast, at 1 MHz the phases and amplitudes are much more favorable. In Figure 3 we show similar plots made at the higher frequency. There is more separation of the 20% notch and the lift-off. Also, the copper signal has rotated around until it is almost horizontal. This considerably reduces the effects of the noise signals on the detection of the defects. There is more phase spread between the 20% and 100% notches, which allows a more accurate sizing.

In Figure 4 we show a scan of the midrange plus-point, using the present phase setting. The indication is barely visible, and was not called in 1997. In figure 5 we show a scan of the same tube using the small, high-frequency plus-point, that has been calibrated in a similar manner. The improvement in the signal-to-noise ratio makes this defect very easy to detect. The reduction in noise will also allow more accurate profiling of the cracks. The signal-to-noise improvement is partially the result of the probe being made smaller also. The new probe has less noise at the 300 and 400 kHz frequencies than the old mid-range probe has.

Measurements will be made on the defects using the new probe and the old probe. The noise will be read from the tube scans at 100 kHz, 300 kHz and 400 kHz for the old probe and at all of the frequencies for the new probe. The measured defect voltages will be compared with the measured notch voltages for the measured defect depths. A more accurate estimate of the ratio between the actual defect voltage and the calibration voltage for the different defect depths will be obtained. It is expected that the defect voltages will be about 10% of the notch voltages for PWSCC cracks of this type. This voltage will be compared to the residual noise voltage in the tubes and an estimate of the threshold of detection for this probe for the u-bend inspection will be made.

The amplitude and phase of the standard notches will be measured at each frequency. These values will be compared to the calculated values. The proper phase setting at each frequency will be determined. This may result in a different calibration phase for the new probe. Setting the phase at too low a value will result in the more shallow defects being missed.

Indian Pt2.nrr

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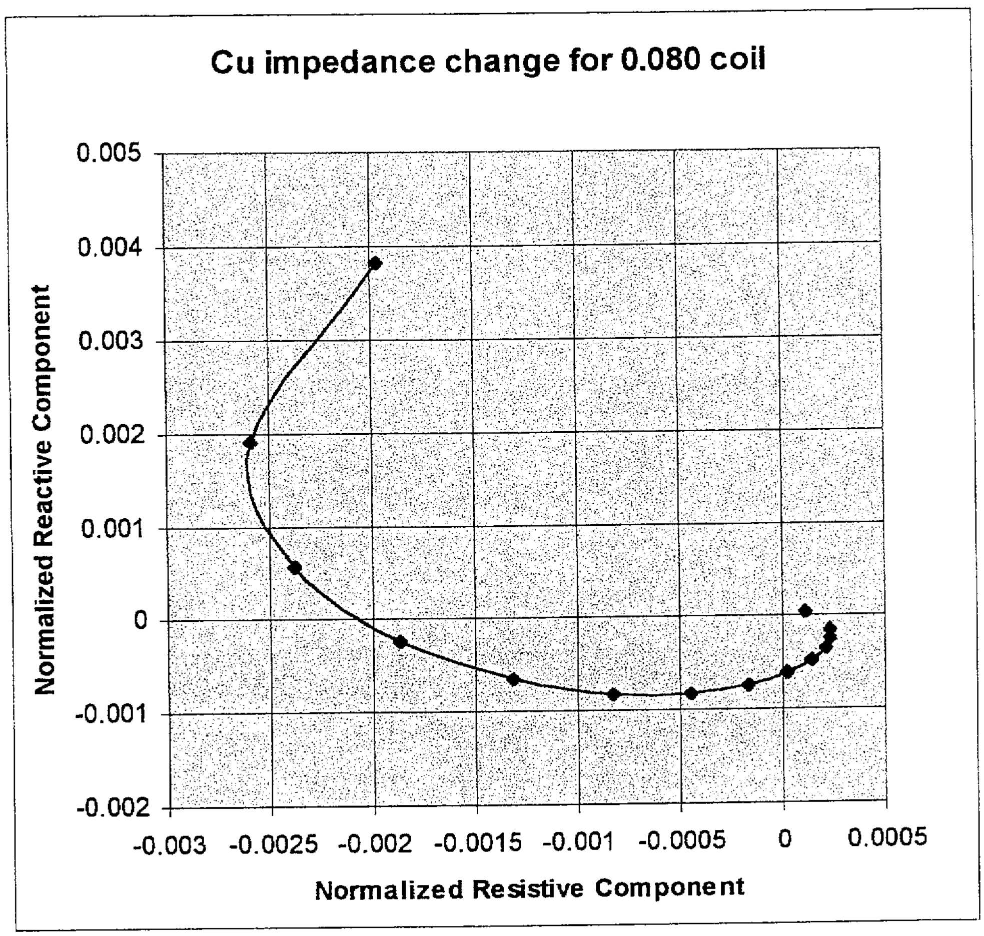

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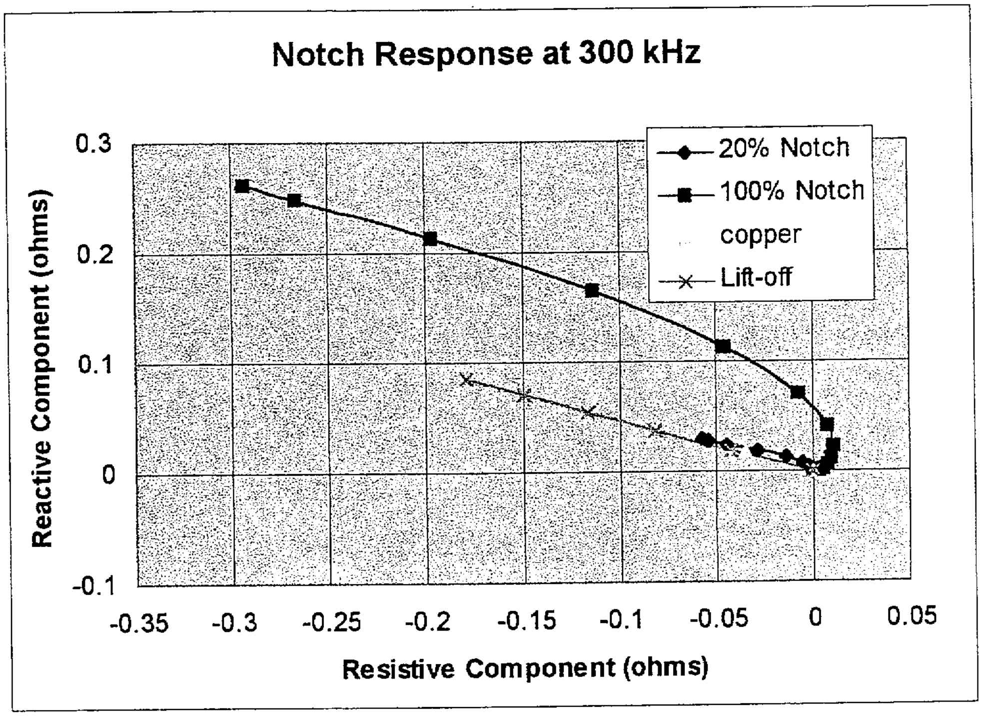

Figure 2 Response of a 0.080-inch probe to notches, copper and lift-off at 300 kHz.

By contrast, at 1 MHz the phases and amplitudes are much more favorable. In Figure 3 we show similar

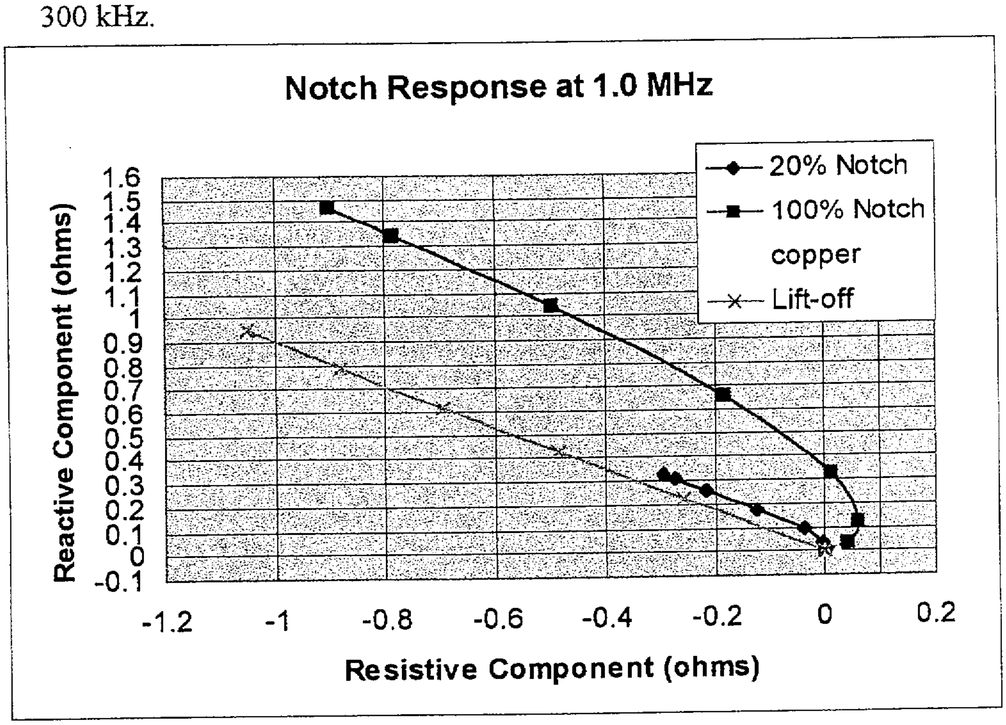

Figure 3 Response of the probe at 1 MHz.

plots made at the higher frequency. There is more separation of the 20% notch and the lift-off. Also, the copper signal has rotated around until it is almost horizontal. This considerably reduces the effects of the noise signals on the detection of the defects. There is more phase spread between the 20% and 100% notches, which allows a more accurate sizing.

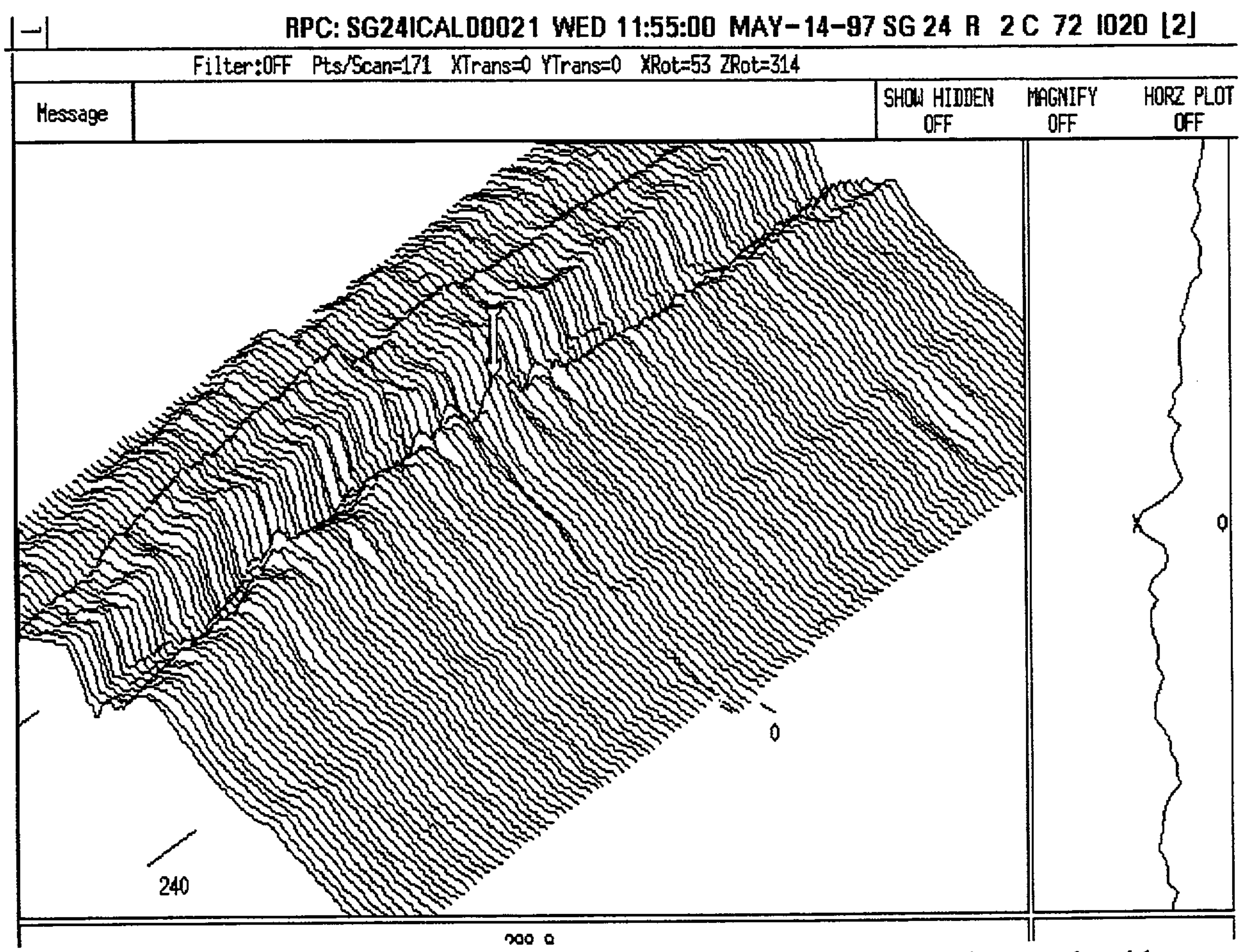

Figure 4 Plot of 1997 scan of tube 2-72 of steam generator 24 made at 400 kHz made with midrange plus-point.

In Figure 4 we show a scan of the midrange plus-point, using the present phase setting. The indication is barely visible, and was not called in 1997. In figure 5 we show a scan of the same tube using the small, high-frequency plus-point, that has been calibrated in a similar manner. The improvement in the signal-to-noise ratio makes this defect very easy to detect. The reduction in noise will also allow more accurate profiling of the cracks. The signal-to-noise improvement is partially the result of the probe being made smaller also. The new probe has less noise at the 300 and 400 kHz frequencies than the old mid-range probe has.

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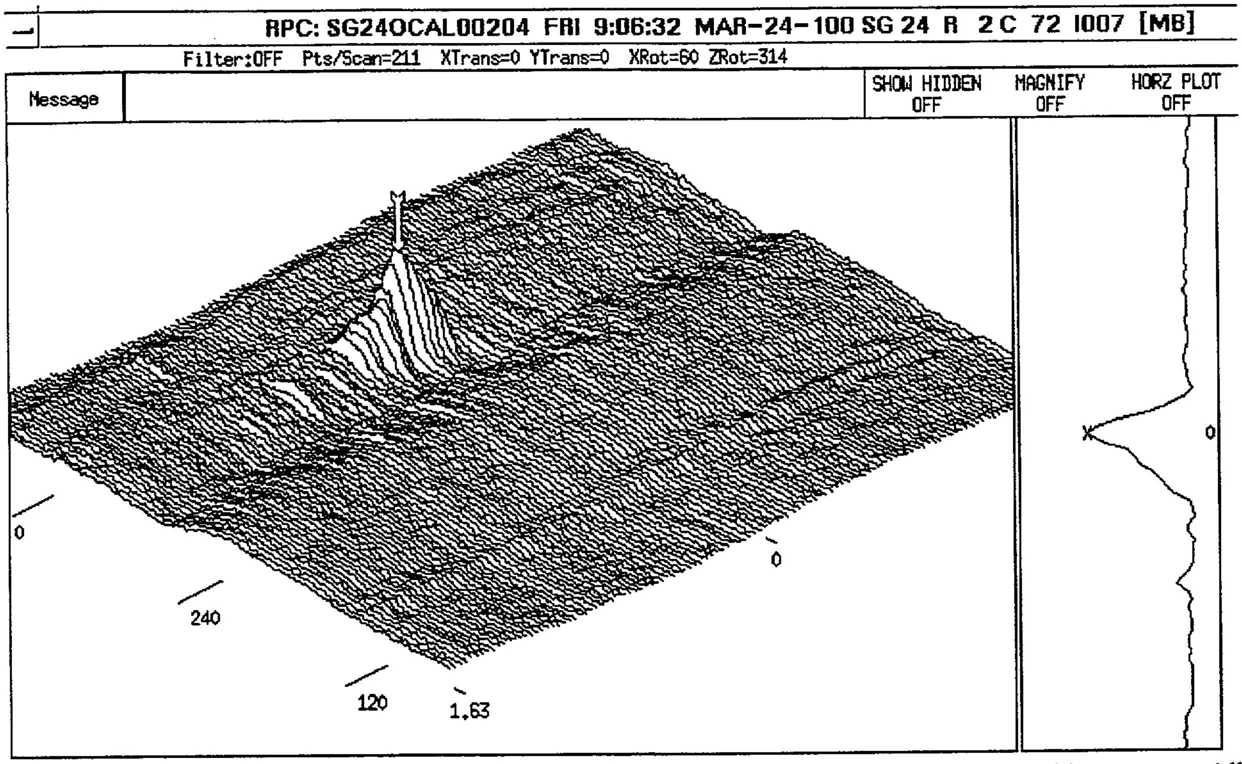

Figure 5 Plot of the smaller, high-frequency plus-point probe at 800 kHz made at this outage. All voltage settings are calibrated at 20 volts on the 100% defect at each frequency.

measured notch voltages for the measured defect depths. A more accurate estimate of the ratio between the actual defect voltage and the calibration voltage for the different defect depths will be obtained. It is expected that the defect voltages will be about 10% of the notch voltages for PWSCC cracks of this type. This voltage will be compared to the residual noise voltage in the tubes and an estimate of the threshold of detection for this probe for the u-bend inspection will be made.

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Noise Reduction for Indian Point

The inspection of the U-bends at Indian Point is thought to be hindered by deposits on the outside of the tubes, suspected of being copper. There are two methods of reducing this noise; increasing the frequency, as shown in Figure 1, or mixing.

Noise reduction by increasing frequency

I have computed the normalized impedance change for a 0.080 pancake probe between no copper and an infinite thickness of copper on the outside of the Inconel tubing. The frequency is increased form 300 kHz to 2 MHz in 100 kHz steps, with a jump from 1.5 MHz to 2 MHz for the last two steps. The amplitude of the impedance change at 1.0 MHz is 17.5% of that at 300 kHz, and the phase has been shifted about 90 degrees. This "noise signal" does not give a straight vector from zero thickness to infinite thickness, but will produce a "fish-hook" shaped vector.

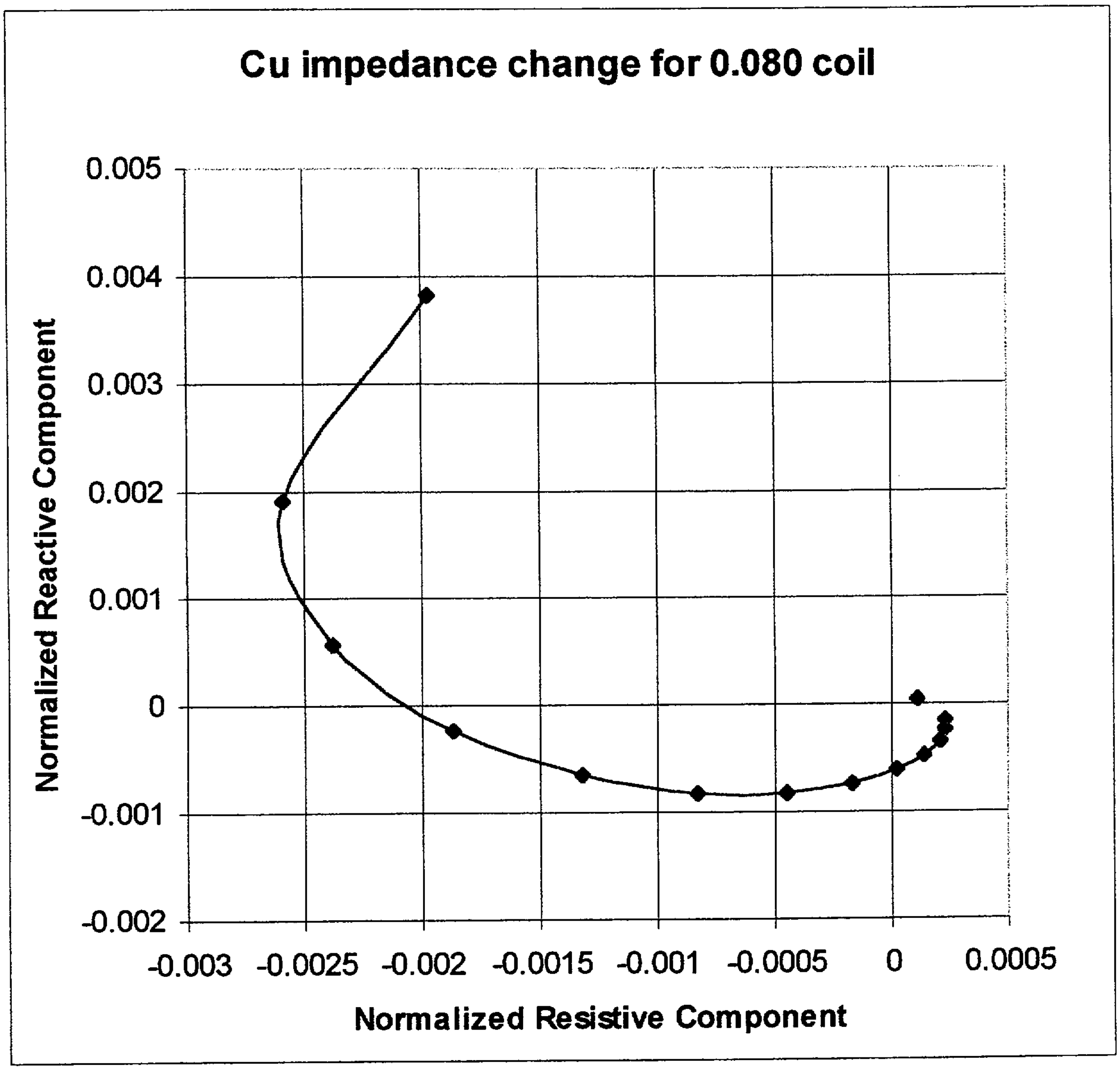

Figure 1 Normalized Impedance change produced by a thick copper coating on an Inconel tube.

Due to edge effects and other geometry variations, the signal can have a number of variations. However, this does give an estimate of the effect. The noise measurements show a predominate signal with smaller variations at other angles. While this gives a rough indication of what may be done, better estimates will come from combined computations and measurements. The VIC-3D program can give fairly good computations for the signals produced by notches of different depths. At least, a 20% id and 100% deep notch should be run. This will provide a phase setting and a better amplitude setting for the test. It will then show how the phase can be adjusted to reduce the noise. The noise can be read from the tube scans at 100 kHz, 300 kHz and 400 kHz. The amplitude and phases between the calculated and the measured noise can be compared, using the calculated and measured notch values. It appears that the noise vectors may be getting more straight as frequency increases, which will also reduce the vertical noise. While this is being run with the 0.080 pancake rather than the plus-point, the results will be similar.

Noise reduction by mixing

"Mixing" is a loose term that has come to mean anything that uses computations to reduce an undesired signal. All signals from anything will rotate in frequency and change in amplitude as the frequency is increased. Artifacts on the tube od will rotate faster than defects within the tube wall. Id defects will rotate the slowest with frequency. I look at how signals rotate in phase with frequency and see if there are improved methods of separating id signals from signals on the od. I will start with simple, computed cases and see if they can be carried over to the more complex cases in the steam generator. If this technique works, it would probably give some aid to signals in the sludge pile. Also, it could be applied to data already acquired, which would help with growth rate calculations.

I will need to get Hal Sabbagh's permission to run the VIC-3D program, since NRC does not own a legitimate copy. I had recommended to Phil that we buy a copy, but it cost about $10,000. However, I believe that he may let me run it.

Indian Pt3.nrv

Settings for the tube calibration

The calibration settings for the inspection with the high frequency probe were investigated. Several different variations were considered. Most of the decisions involve the setting of the phase shift for a defect with zero depth. Since this type of defect produces no signal, it is impossible to set it directly. The first attempt was to determine the setting for the 20%, 40% 60% and 100% phase settings, and extrapolate to the zero setting. However, this produced a calibration curve that would mis-read the 20% depth considerably. In particular, the 20% deep defect can be noisy in many instances, so that the measured depth frequently falls below zero. The calibration curve software does not does not allow for this, so no numerical value is obtained to use in averaging. Another calibration was attempted using the phase of the 40% defect to be set at 12 degrees (which was about 3 degrees higher than the previous setting). This improved the problem somewhat, but the there were still some instances where the depth measured on the standard was still below zero. A final setting of the 40% defect at 15 degrees produced still better results. This is the setting that is presently being used by the utility, and may be the best one. The adjustment of the zero phase shift is critical for inspection of id defects, and needs to be made on a signal that is clean and repeatable.

The reason for setting the phase shift on the extrapolated "zero depth" is to account for the postulated increase in phase shift with frequency for id defects of a given depth. Although there is a considerable increase in phase shift with frequency for od defects of a given depth, this has not been observed for id defects.

It should be noted that this phase setting is somewhat artificially high and it could result in shallow false positive id defect calls. However, in view of the fact that we have found very few measurements on id indications in the 40% deep range, this appears to be justified.

Review of Scans from Indian Point

A considerable number of scans from Indian Point 2 have been reviewed. Several of the defects have been profiled, including one at several frequencies to see the results of the accuracy of the depth measurements at different frequencies. The signal-to-noise has improved considerably, and signals with amplitudes of a few tenths of a volt can be detected. However, with voltages this small, large errors in the phase shift measurements are likely. The larger, mid-range coil has some look-ahead and behind, due to the field spread of the probe. This spread has not been measured for this probe, but its size is about 75% that of the mid-range probe and a similar reduction in the field spread could be expected.

I believe that defect with a maximum voltage of 1.0 volt or higher should be detected. Once this defect has been detected, it can be tracked through the noise as small as about 0.2 to 0.4 volts. However, there will be considerable error in the measurement of the depth at voltages below 1 volt. In Figure 1 we show the profile of the defect in tube R2 C69 of steam generator 24. The tube has been profiled with the high-frequency probe at 1000 kHz and 800 kHz. The depth and the voltage (times 10 to fit on the scale) at each frequency is given. The voltage measured for the 1000 kHz is slightly higher than that for the 800 kHz. The signal-to-noise for the 800 kHz may be slightly better, since od indications are rotated more horizontal, while at 1000 kHz the rotation

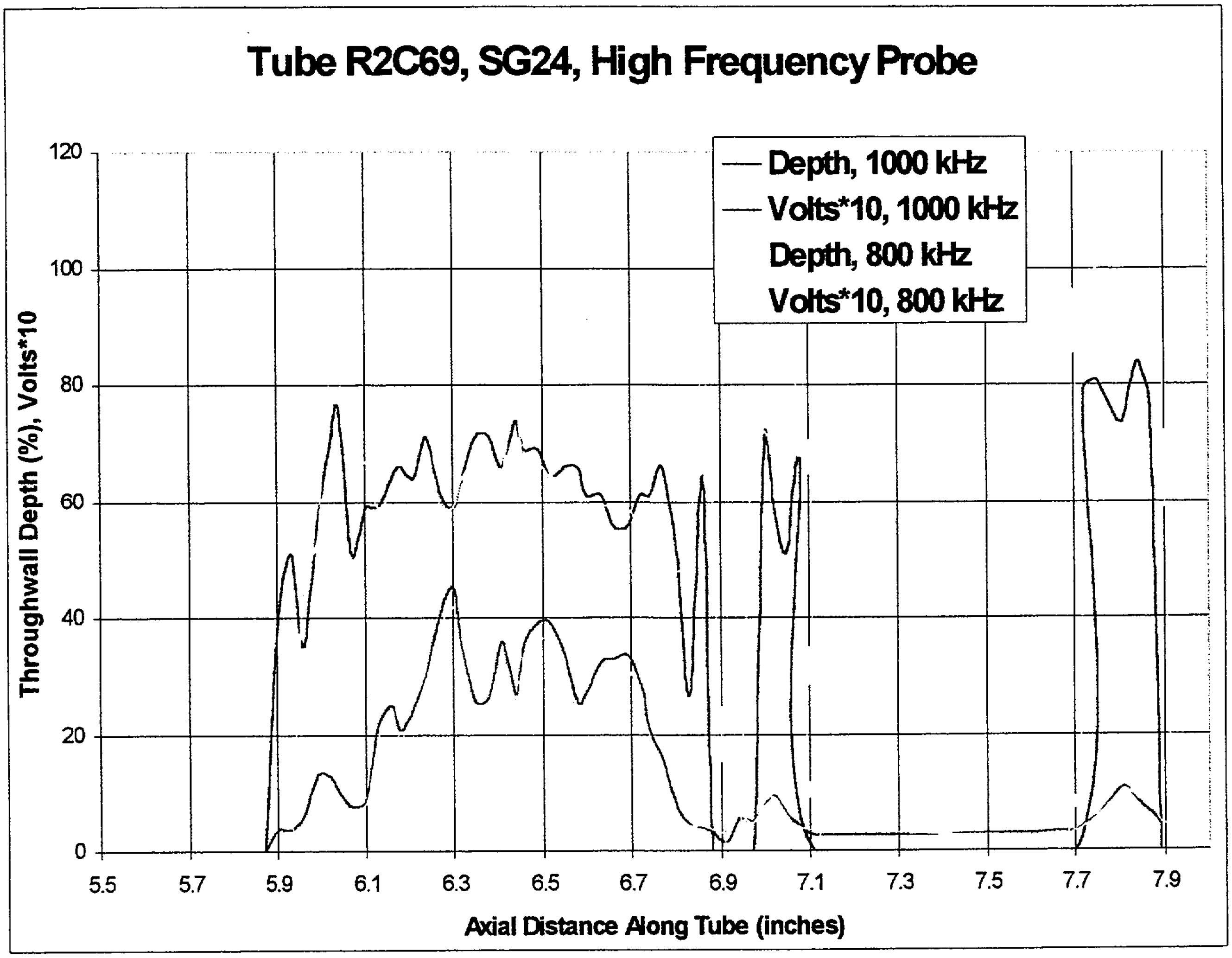

Figure 1 Profile of the defect in tube R2 C69 of steam generator 24 as measured with the high-frequency plus-point at 1000 kHz and 800 kHz.

has gone slightly past horizontal. The depth measured at the two frequencies is about the same. However, this tube had very little noise even with the old mid-range plus-point probe. The indication located at about 7.8-inches has a maximum value slightly greater than a volt, and the agreement between the two frequencies is not as good in this region. This defect at 7.8-inches was not included in the profile mid-frequency plus-point results furnished by the utility.

For indications on the tube id, the voltage increases as frequency increases. The opposite effect is observed for indications on the tube od. Also, for od indications, the phase rotates clockwise as the frequency decreases. For id defects, with the calibration used above, the phase stays constant with frequency. This tube leaked at 5173 psig in the utility test.

In Figure 2 we show the profile of tube R2C71 of steam generator 24. This tube had a small leakage at 2841 psig. The pressure could not be increased past 4500 psig due to the lack of capacity of the pump. Note that this tube was missed in the earlier inspection with the mid-range

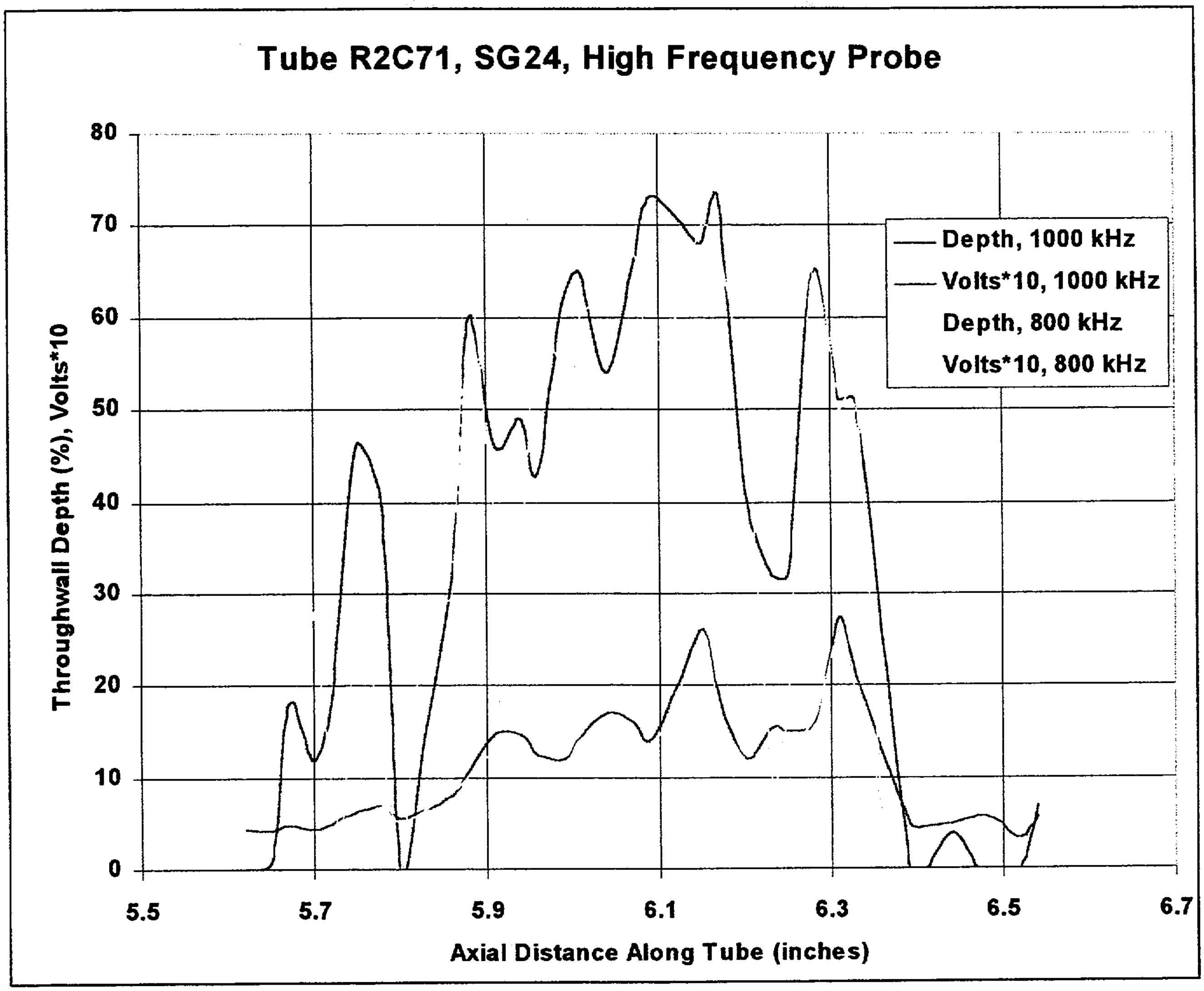

Figure 2 Profile of the defect in tube R2C71 in steam generator 24 as measured with the high-frequency plus-point at 1000 kHz and 800 kHz.

probe. The depth profiles at 1000 kHz and 800 kHz do not match each other as well, which is due mostly to the low voltages that are present. This tube has about the same depth measurements as tube R2 C69 in Figure 1, but the voltage values are only about half as large. Note the depth measurements do not agree well where the magnitude of the voltage is low. When the voltage falls below 0.5 volts, the depth measurement becomes quite inaccurate.

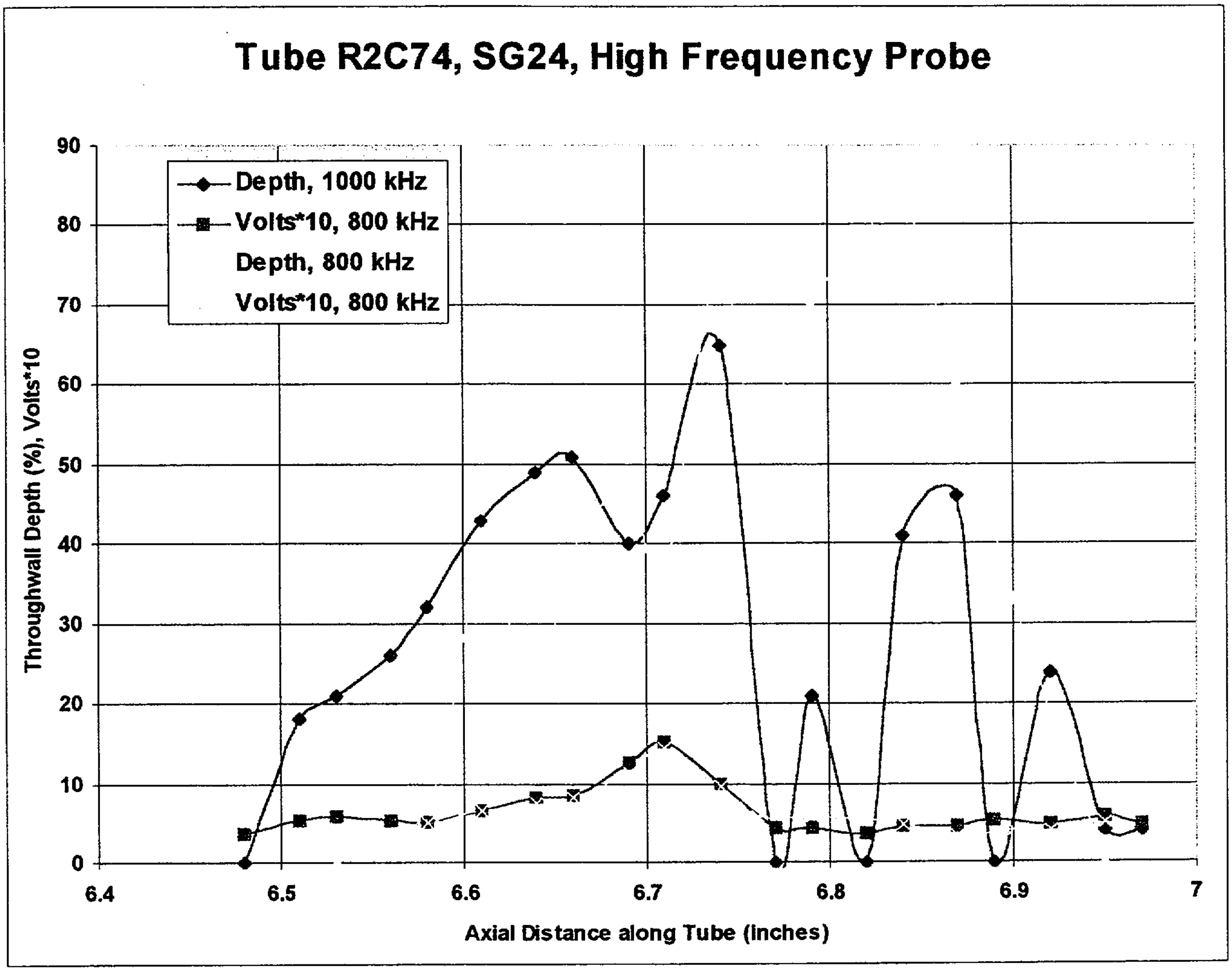

Figure 3 Profile of the defect in tube R2 C74 of steam generator 24 as measured with the high-frequency plus-point probe at 1000 kHz and 800 kHz.

The profile plot for tube 2-74 is shown in Figure 3. The defect has a maximum voltage of only about 1.5 volts. There is very poor agreement in the depth measurement at the edges of the defect where the voltage is small. There was some noise that increased as frequency decreased at the 6.8 to 6.9-inch region of the tube. This tube has a portion of the defect that measures in the 40% to 50 % deep range, between 6.6 and 6.7-inches. This shows some of the probe's ability to measure and detect defects in this depth range. Unfortunately, this tube leaked at 5500 psig.

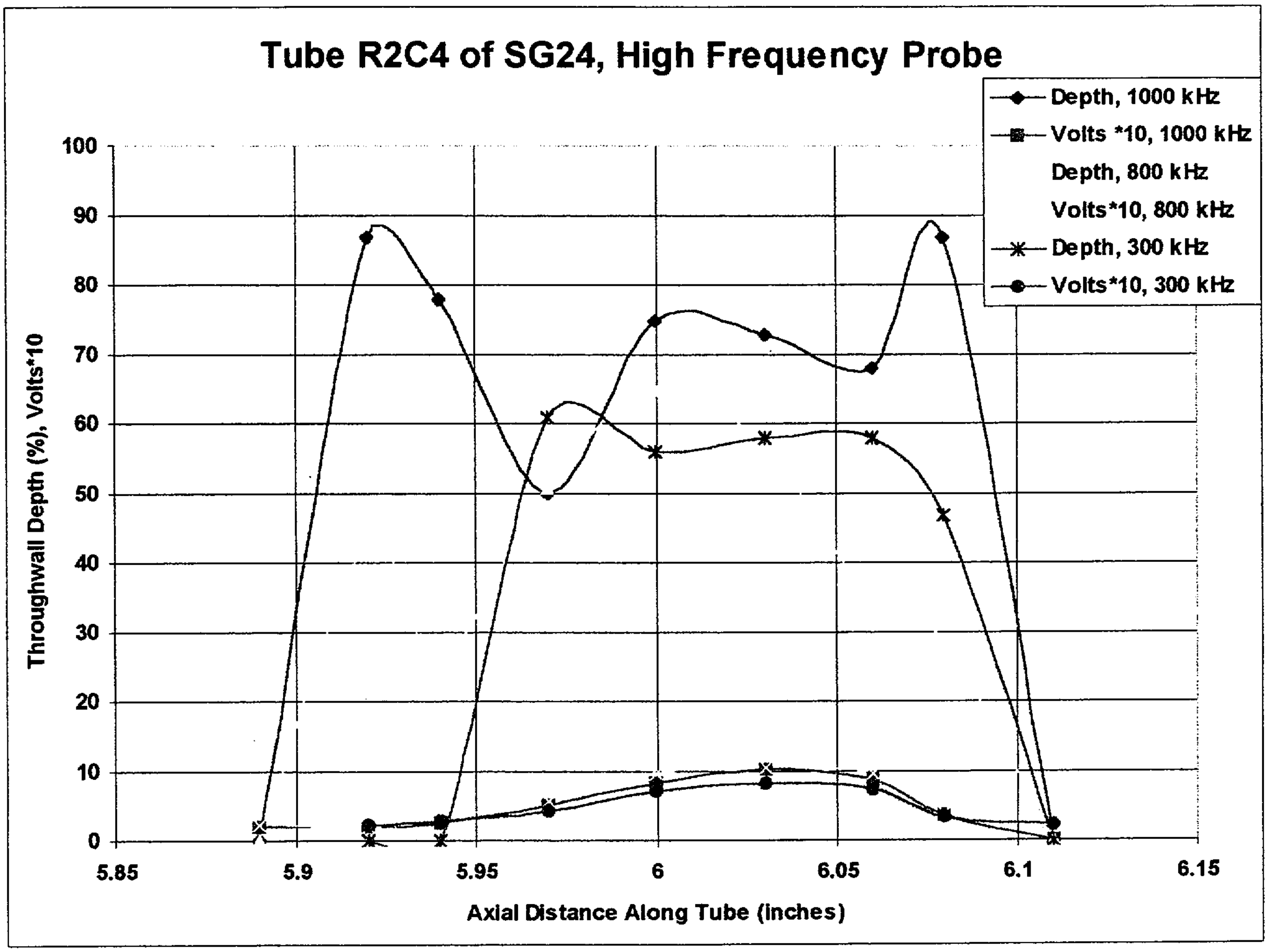

Figure 4 Profile of the defect in tube R2 C4 of steam generator 24 as measured with the high-frequency plus-point at 1000 kHz, 800 kHz and 300 kHz.

In Figure 4 we show the profile of tube R2 C4 of steam generator 24. This tube was profiled with the high-frequency probe at 1000 kHz, 800 kHz and 300 kHz. The maximum voltage measured for this tube was only slightly greater than a volt, which probably has caused the wide variation in depth measurements at the different frequency. This defect is the shortest of all of the defects that we have looked at thus far. This tube did not leak at 5500 psig.

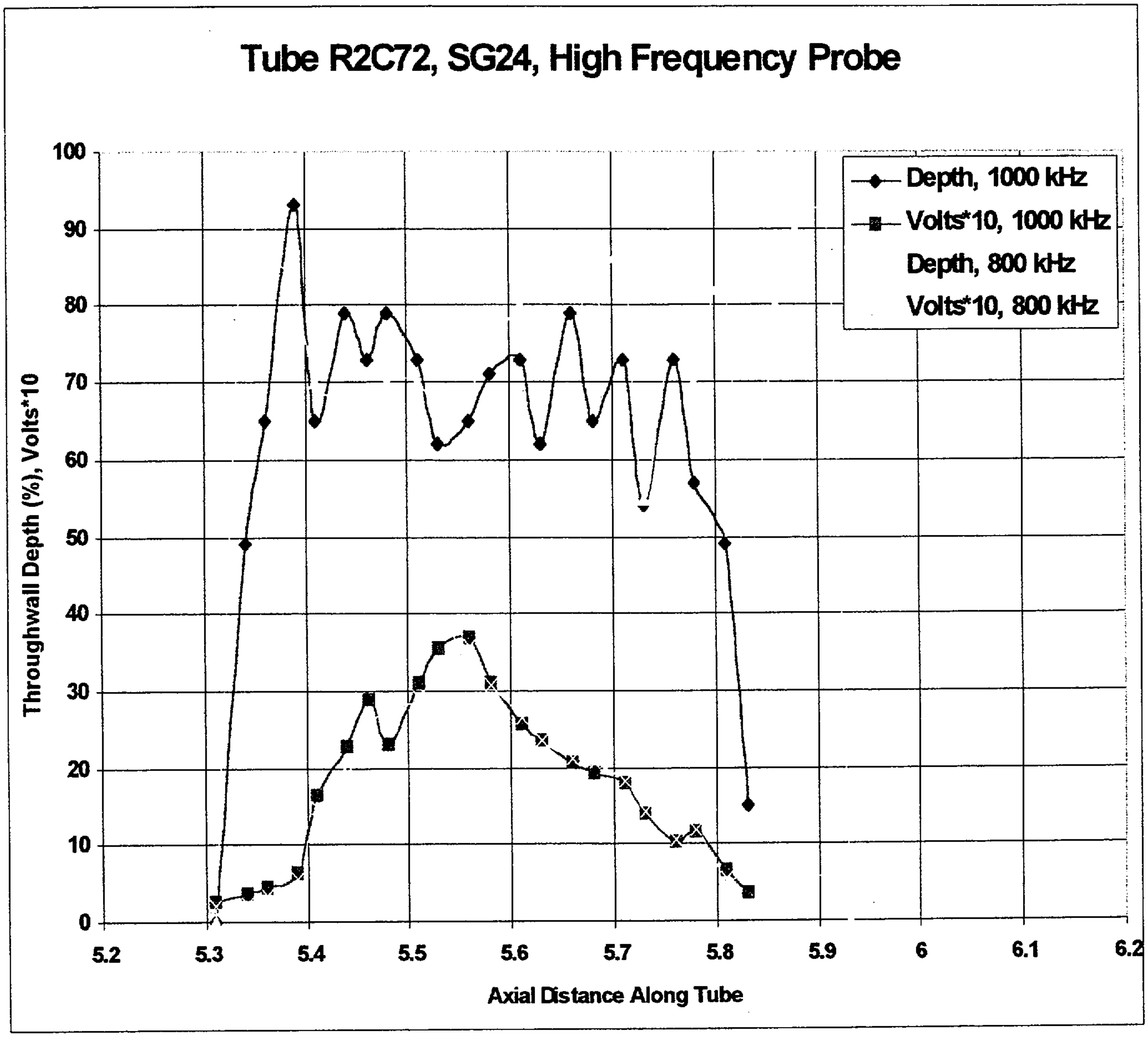

Figure 5 Profile of the defect in tube R2 C72 of steam generator 24 as measured with the high-frequency plus-point at 1000 kHz and 800 kHz.

In Figure 5 we show the profile of tube R2 C72 in steam generator 24. This tube has a relatively high voltage and the phase measurements show a deep depth. However, this tube did not leak at the 5500 psig pressure test, although tubes with more shallow defect measurements and lower voltages did leak. As with the previous tubes, the depth measurements made at higher-voltage agree but not for the lower voltage measurements. There appeared to be od deposits that were influencing the signal at the 5.8 to 5.9-inch location.

Scans on calibration standards

Due to the lack of information on the repeatability and accuracy of the probe, several scans were made on the calibration standard. These are intended to demonstrate the probe's ability to detect and size small defects. It should be keep in mind that the calibration standard produces a larger signal than defects of a similar depth. Also, the calibration standard has none of the od deposits that are present in the generator. Finally, while these notches represent the best approximation to the actual defects that we have, they are essentially two dimensional, while the defects are three dimensional.

Comparisons of the smaller, high-frequency plus-point to the mid-range plus-point
For both probes calibrated at 20 volts for the 100% notch, the new probe gives a larger voltage for the other calibration notches. At higher frequencies, the id notches also give a larger signal on the notches than a lower frequencies. The reverse is true for od deposits and notches.

Widening of the signal due to deposits and lift-off
One source of error is the widening of the defect signal as influences due to od deposits and lift-off modify the signals due to a defect. While the defect may still be detected, the depth measurements, which depend on the phase can be in error. One depth will be measured if the phase is measured from the departing lobe and another if it is measured form the returning lobe. This error can be reduced by averaging the depths measured for each lobe. Figure shows a signal that will give two different depth measurements. Another somewhat easier but perhaps not as accurate method is to use alternate lobes for alternate measurements along the tube and average these results. It should be noted that eddy-current responses are notoriously nonlinear and either of these methods will give limited improvement.

Use of the plus-point at the probe-of-reference in the sludge pile
The utility has stated that the plus-point will be the probe of reference for the inspection of the sludge pile region, as opposed to the bobbin probe. I agree with this decision for the following reasons. The Cecco probe uses transmit-receive coils that are permanently mounted on the coil-holder and not sprung against the side. The coils must be designed with a greater field reach than coils that are surfacing riding. Therefore, they will be more influenced by deposits on the od of the tube than the plus-point. In this regions, these deposits are very plentiful, and this will cause more false positives. In addition, the plus-point reduces the effect of od deposits somewhat due to its differential nature. The probe used in this region has a mid-range plus-point, a high-frequency 0.080-inch pancake and a 0.115-inch mid-range pancake probe. Data from all three coils should be reviewed.

Eddy-current inspection in the sludge pile
There is a noise area near the top of the sludge pile caused by deposits on the od of the tube. These noise signals are the largest in plants that contain copper deposits. If the sludge layer becomes thick enough and uniform enough, the noise signal is reduced. The signal-to-noise ratio for all the eddy-current probes is decreased to the extent that small ODSCC signals could be missed in this region.

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Scans on calibration standards

Due to the lack of information on the repeatability and accuracy of the probe, several scans were made on the calibration standard. These are intended to demonstrate the probe's ability to detect and size small defects. It should be keep in mind that the calibration standard produces a larger signal than defects of a similar depth. Also, the calibration standard has none of the od deposits that are present in the generator. Finally, while these notches represent the best approximation to the actual defects that we have, they are essentially two dimensional, while the defects are three dimensional. In Figure 1 we show a contour plot of the 20% flaw standard. The accuracy of this

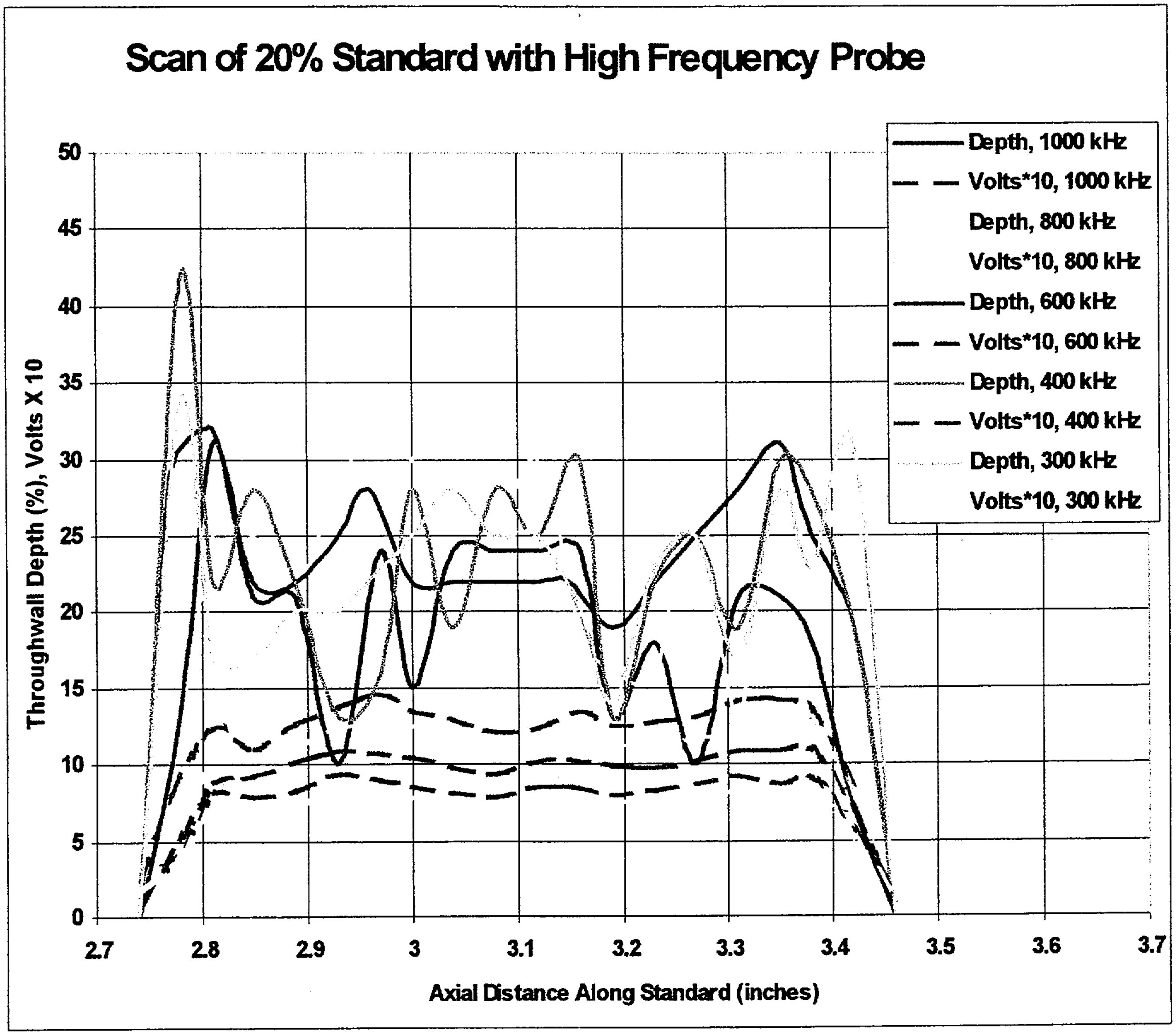

Figure 1 Contour measured on the 20% standard notch at different frequencies with the smaller high-frequency probe.

depth measurement is very poor, due to the small amplitude of the signal and the small amount of phase shift with depth. The notch is only 0.5-inches long, so there is a considerable look-ahead for the probe. The defect signal is about 0.69-inches long if the low-voltage phase measurements are used. It is somewhat shorter(0.65-inches) if the half-voltage value is used. The probe "look-ahead" for this notch is 0.075-inches to 0.095-inches.

In figure 2 we show the measured response of the probe to the 40% notch. The depth spread for this notch is only about 5%, which is much better than the previous one. The ends of the notch

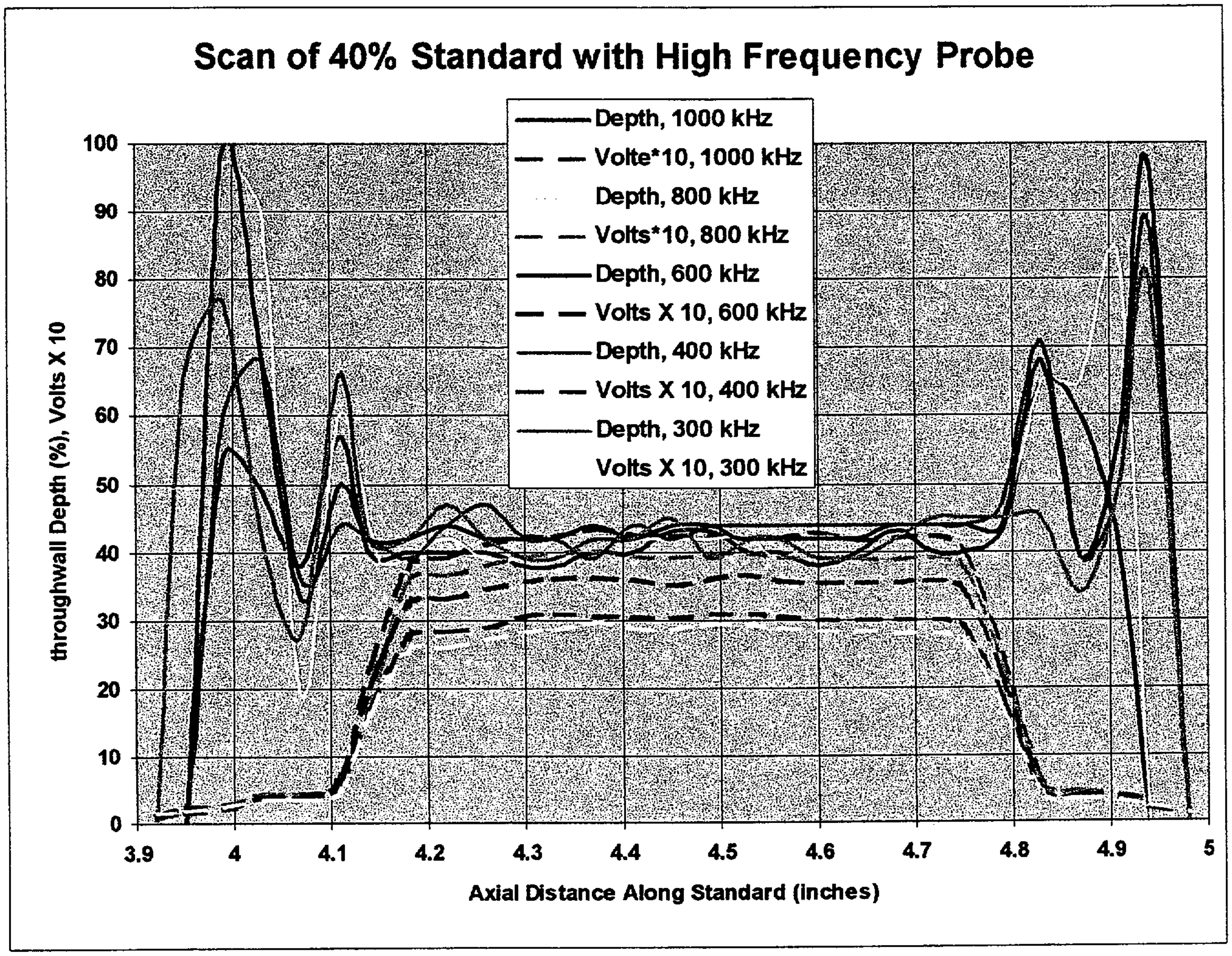

Figure 2 Contour measured on the 40% standard notch at different frequencies with the smaller, high-frequency probe.

produce rather large depth signals, but, due to the very low voltage, would probably not be called. The probe "look ahead", measured from the 0.5 volt amplitude, which is about the smallest that would be used in the field, is 0.11-inches. The 5% depth spread represents only about a 3 degree phase shift, which is about as small as can be reasonably expected. This notch is a much better reference for setting the phase shift on the standard, since its signal-to-noise is much better. The 4-volt signal it produces is much higher than the random noise measured. In determining the 15 degree phase setting for this notch for the calibration set-up, the analyst should make several measurements along the notch to see which ones are the most stable and use that one.

In Figure 3 we show the response of the probe to a 60% notch. This response is more like that of the 40% notch. The depth spread is only about 5% total, and the notch edges produce a apparent

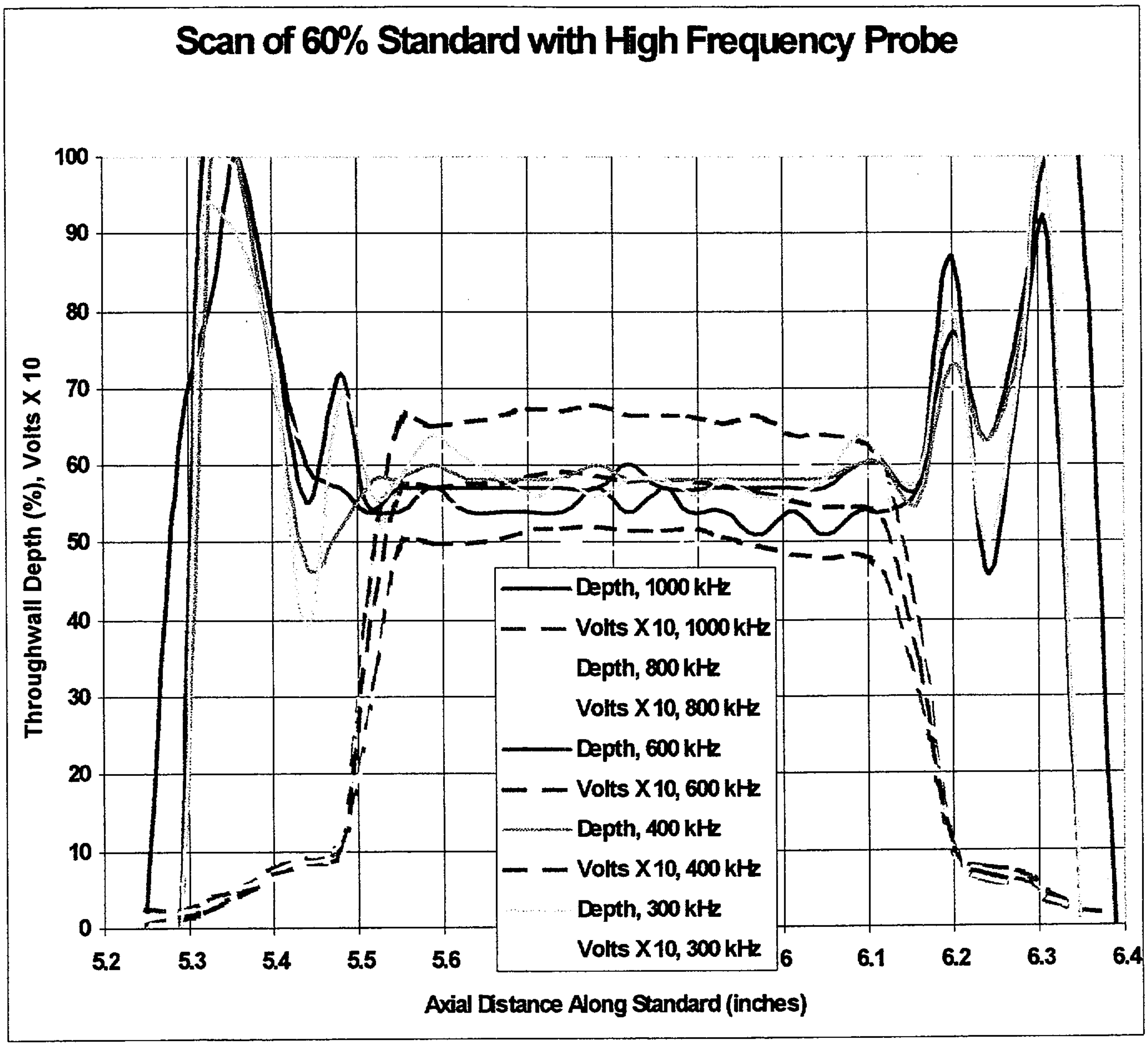

Figure 3 Contour measured on the 60% standard notch at different frequencies with the smaller high-frequency plus-point probe.

deep signal at the notch edges. The edge values were clipped at 100% deep, since the software does not allow depths beyond that. When the phase exceeds the 100% id value, the defect becomes an od defect, with values decreasing from 100% as the phase increases. The "look ahead" for this probe is somewhat larger, depending on the amplitude value that we use as the "cut-off" value. If 0.5 volts is used, the "look-ahead" is 0.22-inches. If we assume that the field defect will only produce about half the signal that a notch does, the "look-ahead" will be only 0.11-inches.

The amplitude that an IDSCC indication produces depends on how many ligaments are conducting eddy-currents across the crack face. The contaminants that produce the corrosion are insulating at room temperature, but due to the path of corrosion, there can be "good material" that bridges the crack face and conducts the currents, reducing the eddy-current signal from that of a notch. The stress-corrosion cracks have complex, three-dimensional structures and are not well represented by notches until they become large and have opened up somewhat. Their signal amplitude will vary with cracks of the same depth. The ones that we have seen and contoured have amplitudes from 50% of that of a notch (tubes 2-69, 2-71, 2-72) to 15% (tube 2-24). We may be over estimating the signal amplitude that the average notches produce since we would only detect the notches that produce the higher amplitudes. This is why it is important to pressure test some NDD tubes to see what opens up, even if it does not leak. I do not know that there are a population of defects in the tubes that we still are not detecting, but there is that possibility.

Using the value of 50% for the IDSCC voltage amplitude correction, we would use 0.11-inches for the larger defects, down to 0.075-inches for the smaller defects. The depth values of the crack-tails, measured at low voltages, should be discarded.

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Comparison of tube scans before and after pressure testing

Scans were made on the three leaking tubes in Steam Generator 24 after the pressure tests. These scans revealed a considerable change in the eddy-current response. Of most interest is the scan of 2-69. In Figure 1 we show the pre-pressure test scan of this tube, with the post-pressure test of

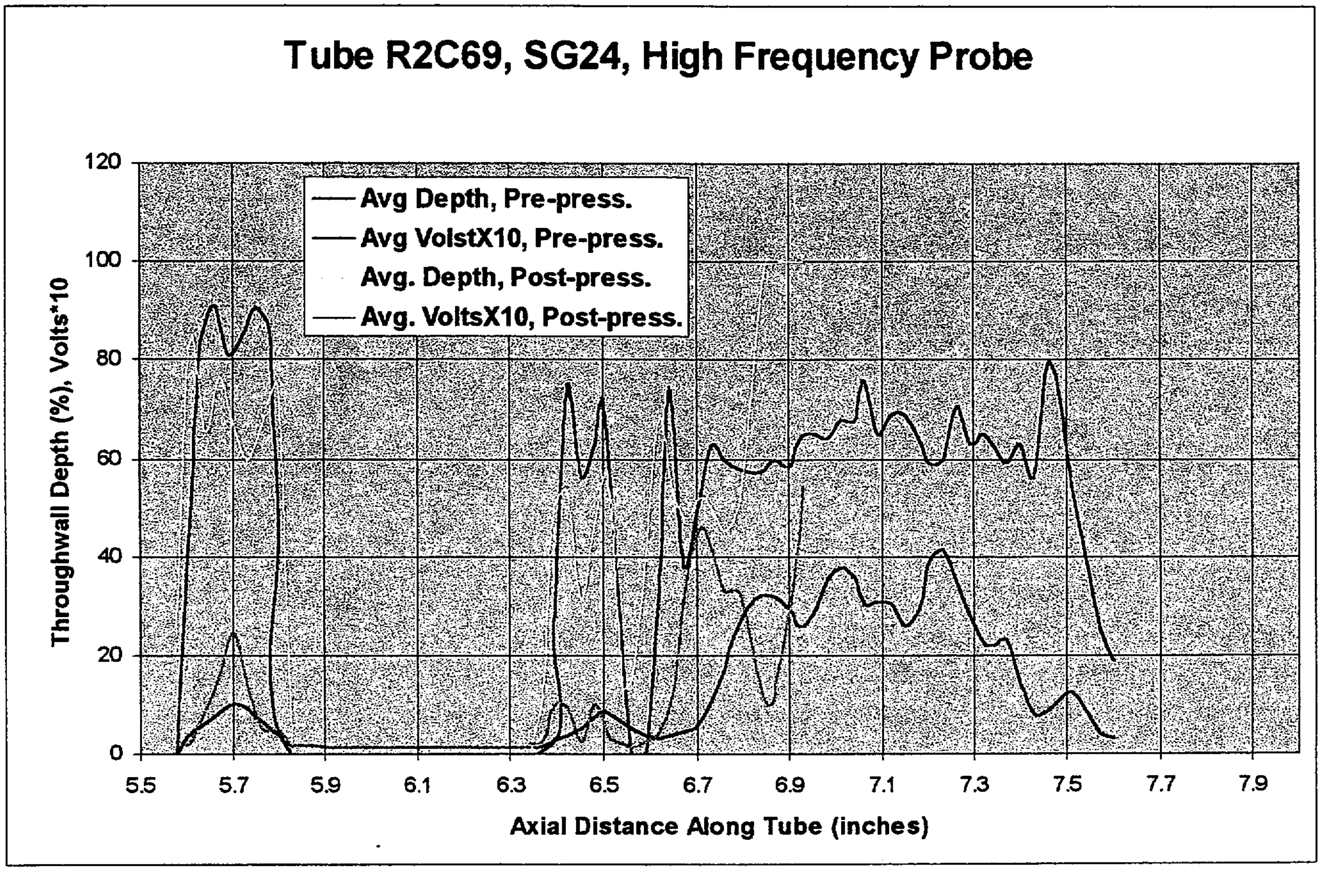

Figure 1 Profile of tube R2C69 showing the effect of pressurizing the tube.

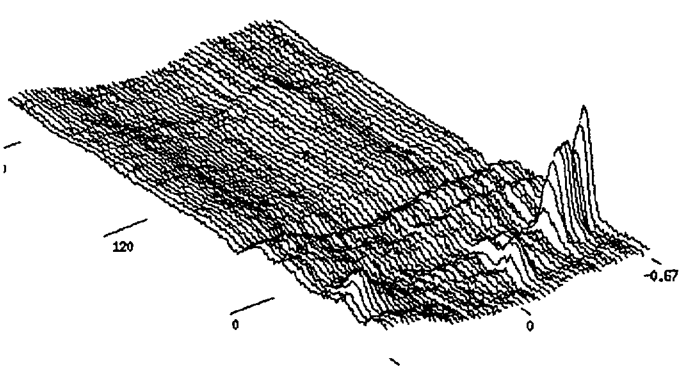

Figure 2 Pre-scan of R2C69 of SG 24

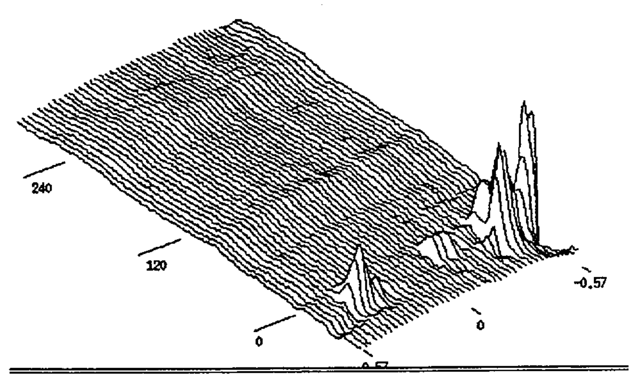

Figure 3 Post-scan of R2C69 of SG24

the tube superimposed. The region on the right has only the pre-pressure test scan, since the probe would not run through the tube after the test. The amplitude of the scan is large enough to be more accurately measured. Figure 2 has the pre-scan graphics and Figure 3 has the post-scan

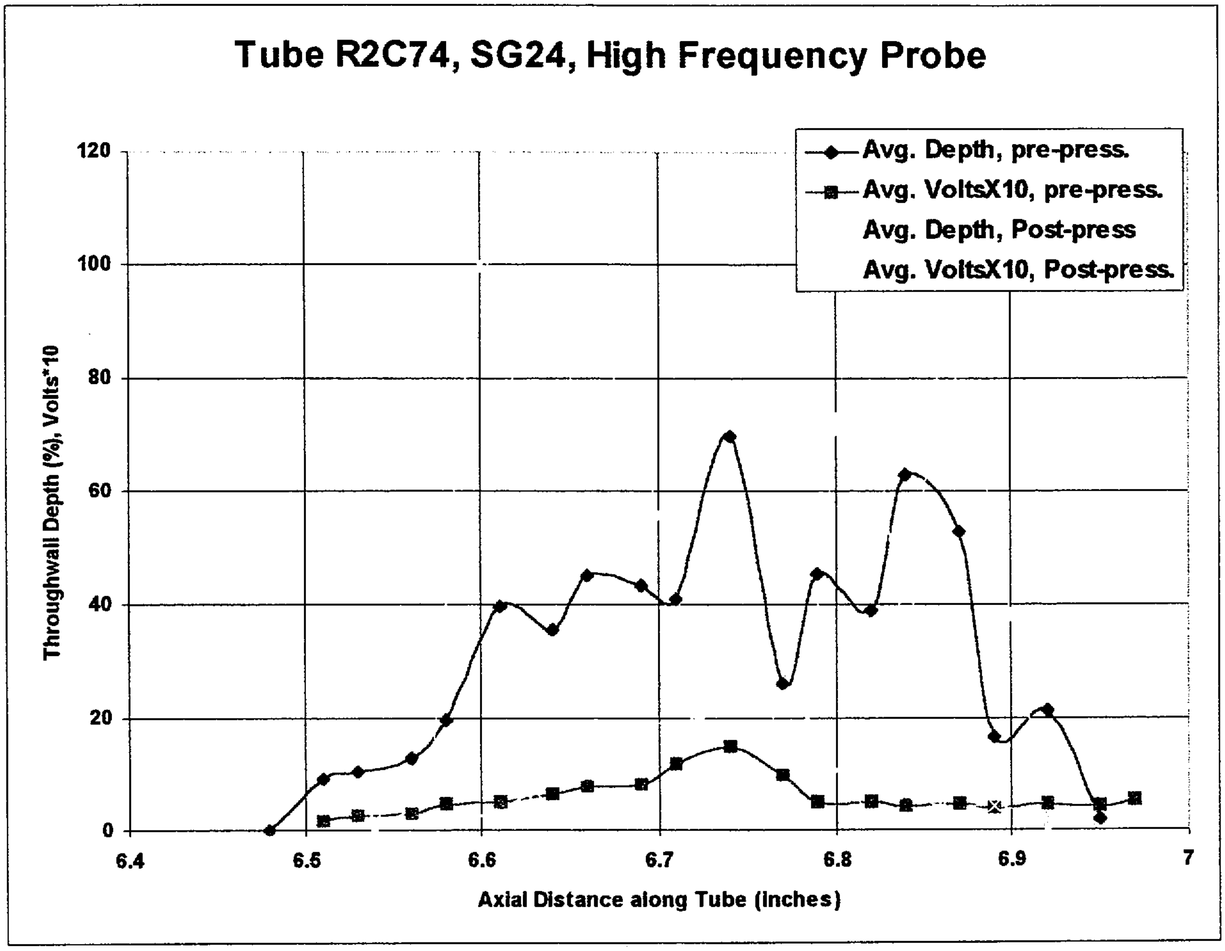

Figure 4 Profile of tube R2C74 of steam generator 24 showing the effects of pressure testing.

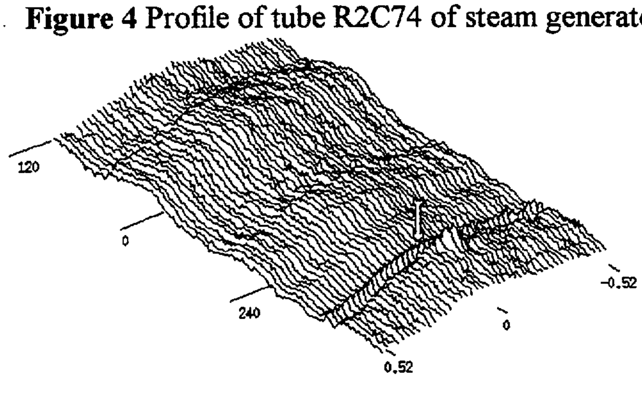

Figure 5 Pre-scan of tube R2C74

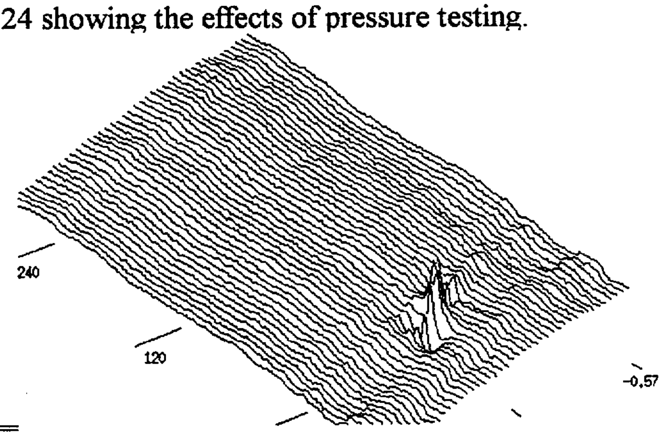

Figure 6 Post-scan of R2C74

graphics. The defect on the left was not included in the profile of this tube, but it was reported on the data sheets. In Figure 4 we show the profile of tube R2C74 of steam generator 24, and in

Figure 5 we show the pre-scan of tube R2C74 and in Figure 6 we show the post scan. The defect has penetrated the wall and this tube, as with the other two, leaked. The signal-to-noise is better, due in part to the increased signal in the post scan.

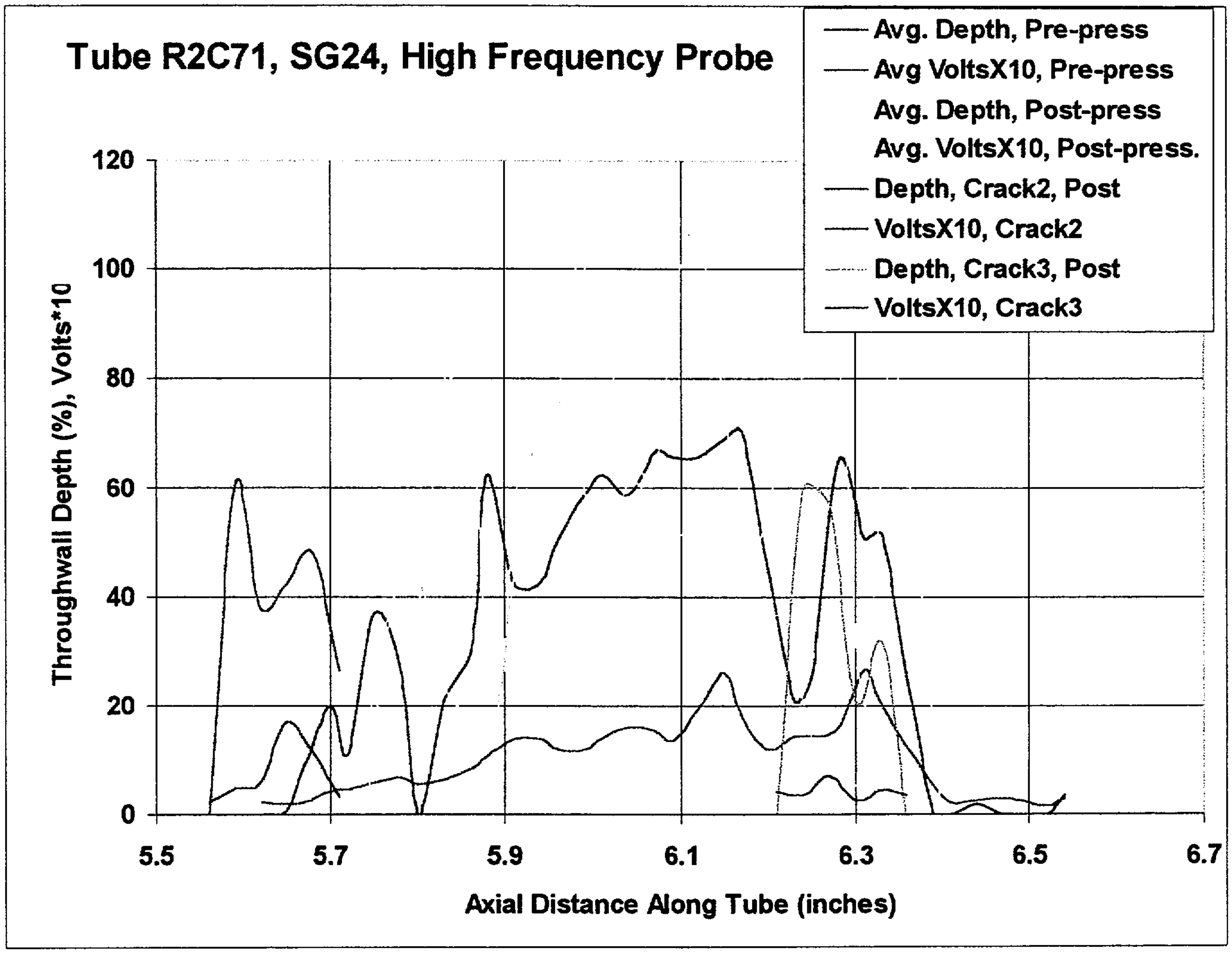

Figure 7 Profile of tube R2C71 of steam generator 24 showing the effects of pressure testing.

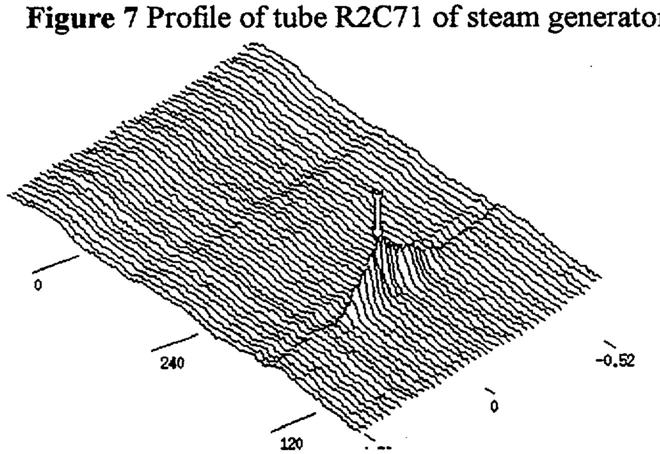

Figure 8 Pre-scan of tube R2C71

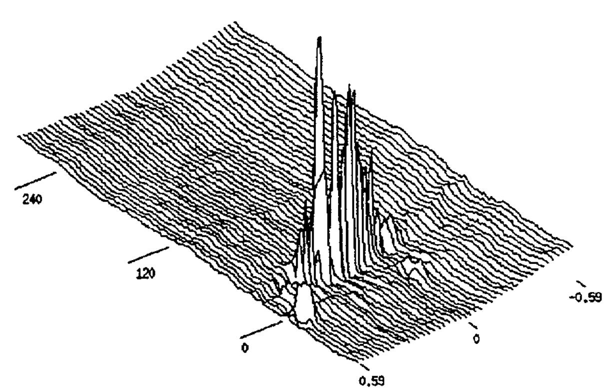

Figure 9 Post-scan of tube R2C71

The pressure testing of tube R2C71 of steam generator 24 shows the presence of two new cracks that were not visible on the scan of the pre-pressure test scan. It is unknown if the cracks were there previously or were created by the pressure testing. However, they are clearly visible now, and they are profiled as crack2 and crack3 in Figure 7. If these cracks were present before the testing their amplitude was too small for them to be detected and sized. In Figure 9 these cracks appear in the foreground, where they were not visible in the scan in Figure8.

In Figure10and in Figure 11 we show the profile of cracks found in tube R2C87 of steam generator 21. This tube had a secondary crack about 0.35-inches long with a depth of about 70% of the wall. The voltage amplitude of this crack has approximately doubled with the pressurization. The depth appears slightly less and the length appears slightly longer after pressurization, but this is probably due to the crack being easier to detect at the edges, and the measurement is probably more accurate with the larger voltage.

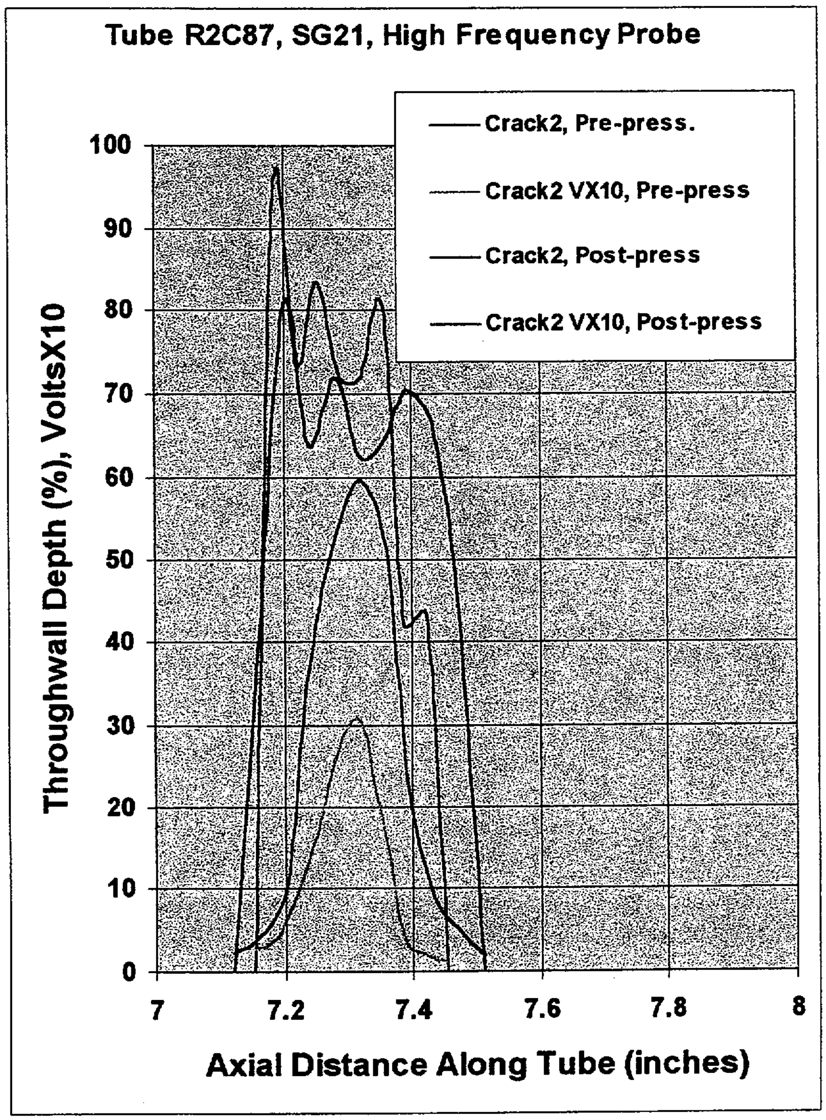

Figure 10 Profile of secondary crack in tube R2C887 in steam generator 21 before and after pressurization.

The primary crack shows a similar change with pressurization. It appears to be between 60 to 70% deep, with two ligaments of conducting material across the crack face. The overall length of the crack is about 2-inches. There is a bridge from about 7.1-inches to 7.3-inches and another from about 7.8-inches to 8.2 inches. The crack depth probably does not go to zero along these bridges, but down to a value (20% or less, after pressurization) small enough not to be detected. In Figure 12 we show the pre-scan of tube R2C87, showing both of the cracks and Figure 13 shows the post-scan of the tube. It appears that the defect was scanned from different directions (the pull on one scan and the push on the other scan) between the two scans. The scans can be made to have

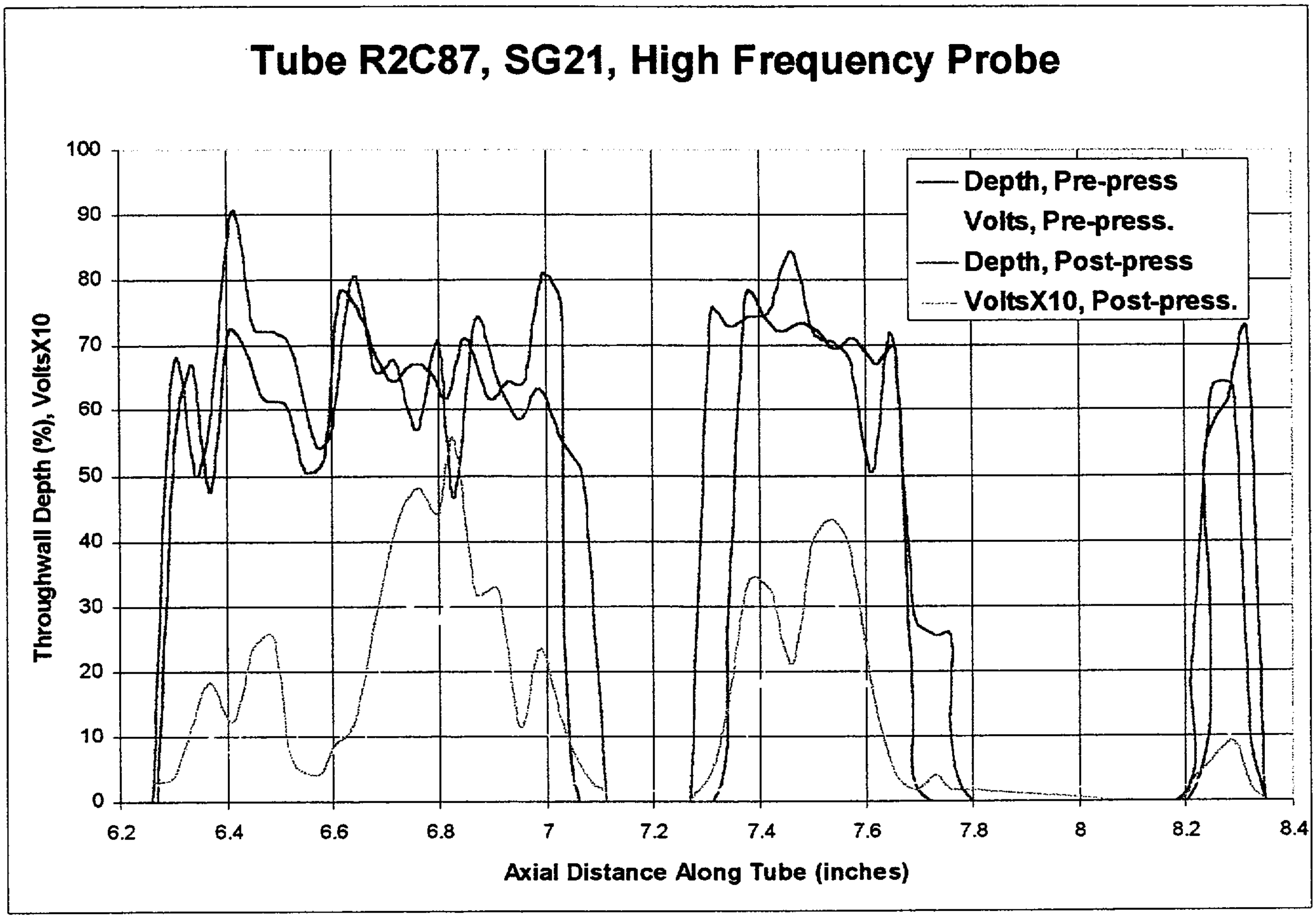

Figure 11 Primary crack in tube R2C87, steam generator 21, before and after pressurization.

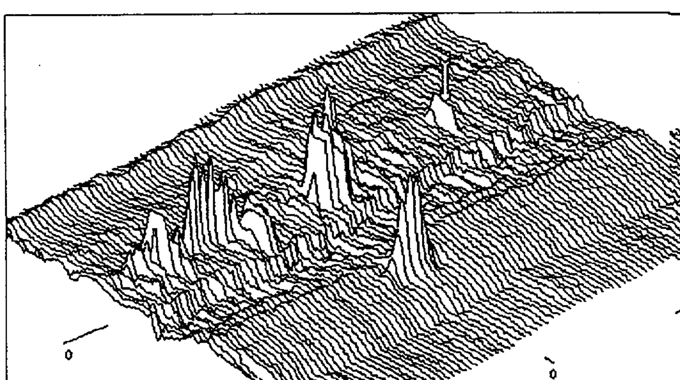

Figure 12 Pre-scan of tube R2C87 of SG21.

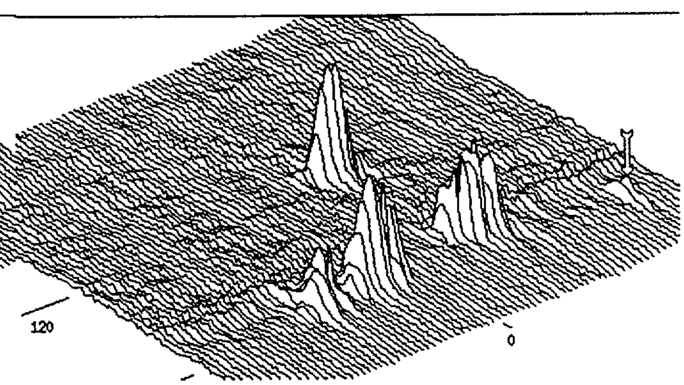

Figure 13 Post-scan of tube R2C87 of SG21

the same axial orientation, but this results in the secondary crack being on different sides of the primary crack.

In Figure 14 we show the effects of pressure testing on the crack found in tube R2C85 of steam generator 23. This crack showed the same phenomenon as the others, to a lesser extent. The depth appears to be about the same and the length appears to increase slightly. In Figure 15 we show a C-scan of the tube before pressure testing and in Figure 16 we show a scan of the tube after pressure testing. The scans in this case are quite similar, with no new cracks appearing.

In some cases the post-pressure test scan shows a deeper crack than the pre-scan test. This probably reflects the uncertainty in the depth measurements of the low amplitude signals more than anything else. However, it could be due to the inner portions of the crack producing a larger amplitude signal than the outer portions, due to the inner portion opening more. The vector result of the combined signal, which is what the eddy-current probe sees is therefore biased to the more shallow portion of the crack, and the result appears as a more shallow crack. This same phenomenon was observed for the IGA on the inner surface of the tube after pressurization at Three Mile Island, Unit 1.

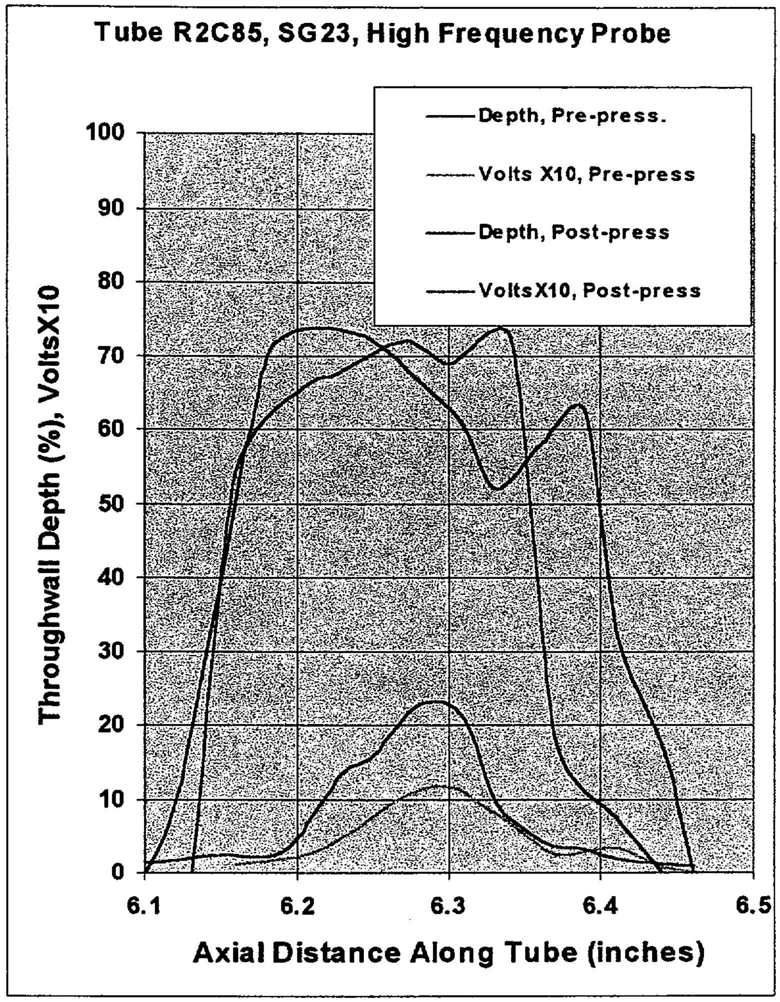

Figure 14 Profile of tube R2C85 of steam generator 23 showing the effects of pressure testing on the crack.

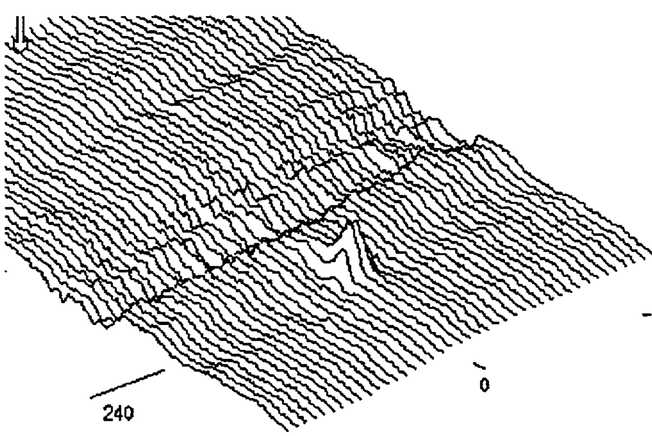

Figure 15 Pre-scan of tube R2C85

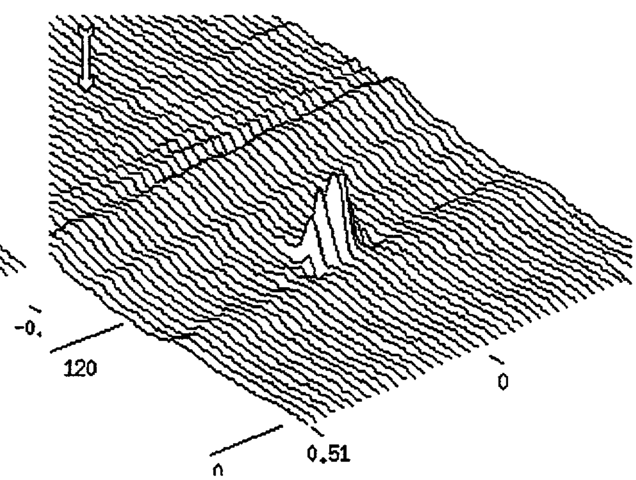

Figure 16 Post-scan of tube R2C85

None of these profiles are adjusted for the edge effects that the plus-point (and other eddy-current) probes will produce. For the low level signals, small noise perturbations can cause large errors in the depth readings, particularly for signals under a volt in amplitude. The analyst uses a certain amount of judgement in profiling these cracks, and the readings are influenced by what the analyst believes the crack should look like.

These profiles and scans clearly show how the detectability of these small u-bend defects is increased due to the pressure testing of these tubes. Although it varies from crack to crack, the amplitude of these small cracks increases by about a factor of two due to the pressurization.

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Signal-to-noise measurements made in the sludge pile region:

Signal-to-noise measurements were made on selected tubes with defects in the sludge pile region by Andy Neff. These measurements were made for the bobbin, Cecco and plus-point probes. The bobbin and Cecco had measurements made in 1997 and 2000. The plus-point probe had only scans made in 2000. The measurements are only approximate, and the Cecco signal measurements can only be compared to the noise measurements. The noise measurements made for the bobbin and Cecco probes were only in the vicinity of the axial defects. The noise measurements made for the plus-point included the entire sludge pile span. The measurements were less noisy near the top of the tube sheet than they were on up near the top of the sludge pile. The sludge pile noise was also present on the cold leg, although to a lesser extent. These first three tubes had clear plus-point hits that were definitely cracks above the top of the tube sheet.

Tube	Probe	Year	Signal Voltage	Noise Voltage
35/51 SG22	Cecco	1997	13.66 volts	28.17 Volts P-P
	Bobbin	1997	0.71 volts	1.59 Vert Max
	Cecco	2000	10 volts	32 Volts P-P
	Bobbin	2000	1.22 volts	1.82 Vert Max
	Plus-point	2000	0.70-volts	0.3 Vert Max

Tube	Probe	Year	Signal Voltage	Noise Voltage
34/51 SG22	Cecco	1997	7.38 volts	8.37 volts
	Bobbin	1997	2.51 volts	3.02 Vert Max
	Cecco	2000	15.81 volts	26.49 volts
	Bobbin	2000	2.71 volts	3.75 Vert Max
	Plus-point	2000	0.87-volts	0.3 Vert Max

Tube	Probe	Year	Signal Voltage	Noise Voltage
29/46 SG23	Cecco	1997	1.69 volts	1.7 Vert Max
	Bobbin	1997	3.6 volts	3.6 volts
	Cecco	2000	11.75 volts	11.75 volts
	Bobbin	2000	3.06 volts	3.0 Vert Max
	Plus-point	2000	0.37-volts	0.3 Vert Max

A sample of about 10 additional tubes were looked at in the sludge pile region, to gage the noise of the plus-point probe, some being from the hot leg and some being from the cold leg. The noise level in this region increased as high as 0.5 volts Vert Max. No doubt that the noise level is higher on some tubes that I did not examine.

The tubes in the table were only called by the secondary analyst, although they had a good signal-to-noise ratio. The reason that these tubes were missed should be followed up by the utility since they represent a breakdown in the inspection process.

There were also tubes on the pressure-testing list that were not defective tubes. Tube 42/43 of steam generator 24 showed two low-amplitude, shallow crack-like indications, one having an amplitude of 0.12-volts and the other having an amplitude of 0.31 volts. Niether the amplitude or the phase of these indications changed during the pressure testing. Therefore, if these were actual defects, I would conclude that they do not degrade the tubing. Most likely they were od artifacts in the coating on the tube. The utility is probably plugging a number of tubes similar to these.

Several pit calls in tubes 45/51 and 17/63 of SG24 were also reviewed. These were, in my opinion, harder to call than the axial cracking. The signal-to-noise is somewhat poorer for the pits, and they are only picked out of the noise by their shape. The pit test is marginal, but these indications probably do not constitute a danger to the tube integrity. While there is a clear difference between pitting and larger volumetric indications with clean, low-noise measurements, it is not always apparent for the field tests. However, this also does not make much difference in the tube integrity. Volumetric indications will produce larger voltage signals than the pits, and therefore be easier to detect.

The EPRI pit sizing for the bobbin probe used 64 calibration points, 55 of which were machined defects. The machined pits are easier to detect, more uniform, and have less noise signals than the pulled tube pits. I fell that this may have biased the qualification test and question its validity. I also believe that pit sizing with the rotating probes will be more accurate. The operating frequency should be expanded to higher frequencies to eliminate the influence of od deposits. This will provide a screening for the deeper pits, which we need to insure that are not missed.

Some advanced mixing methods may be able to improve the signal-to-noise in this region, but this is not available at this time. The utility has improved the inspection considerably in the u-bend region, where it is probably adequate at this time. The test will probably not detect all defects smaller than 60% at this time. However, the missed defects are probably quite short and the tube would not rupture under accident conditions. At my suggestion, a few tubes were inspected using the high frequency probe in the sludge region. The data from these scans were of poor quality and no conclusions could be drawn from this test.

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Phase settings between 1997 and 2000

In 1997 the phase rotation for the eddy-current calibration was set too low, resulting in a decrease in the vertical signal that the analyst uses for screening for defects. In Figure 1 we show the c-scan plot with the phase set too low. In Figure 2 we show the phase setting that is being used for the current inspection. The indication, which is riding on a noise ridge, is easier to see.

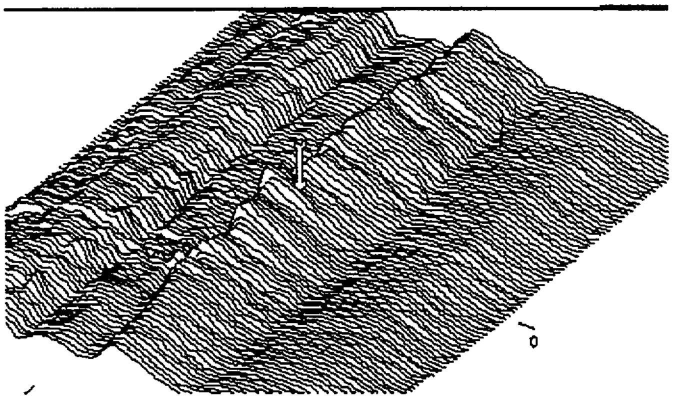

Figure 1 C-scan with1997 phase setting.

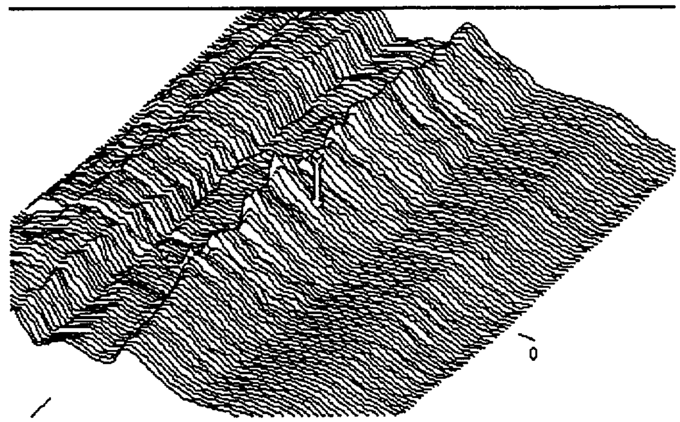

Figure 2 C-scan with the 2000 phase setting.

With proper training the analyst would be more likely to discover the indication with this phase setting. In Figure 3 we show the Lissajous of the indication that the arrow is pointed to.

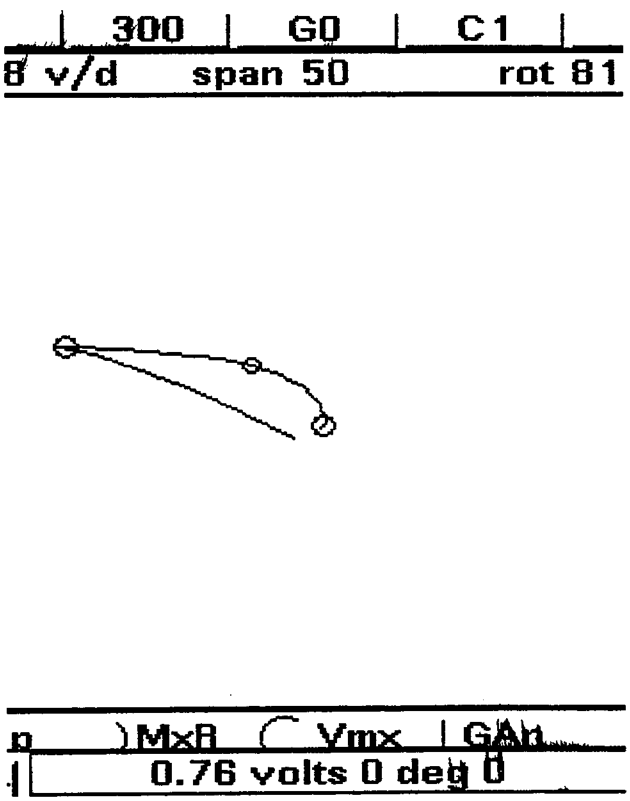

Figure 3 Lissajous of defect with 1997 phase setting.

The vertical signal with the correct phase

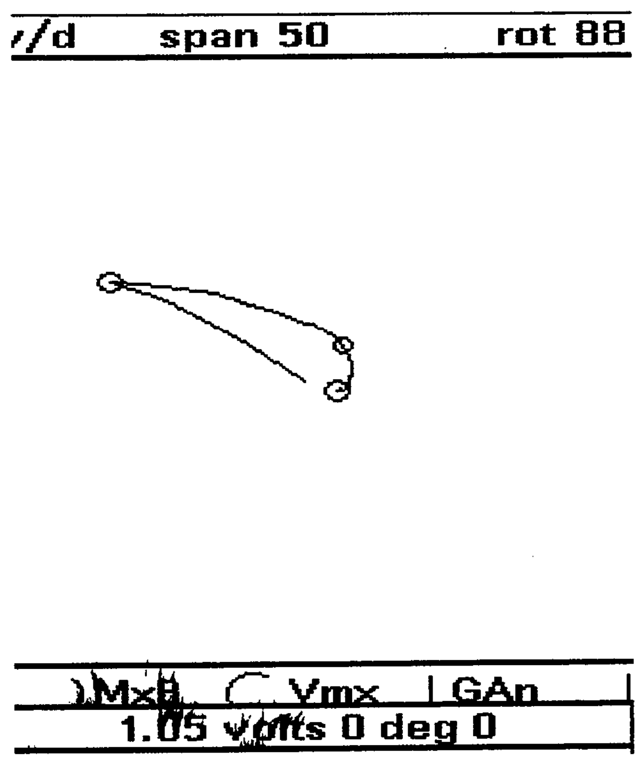

Figure 4 Lissajous of defect with 2000 phase setting.

setting changes from 0.76-volts to 1.05-volts, giving the analyst an increased chance to notice the defect. When the analyst notices the defect, he will then click on it and make a reading from the lissajous screen. The shape of the indication clearly identifies it as a crack in both Figures 3 and 4. It is slightly easier to spot in Figure 2 than it is in figure 1, due to the increased vertical amplitude. The phase setting of Figure 1 is 7 degrees lower than that of Figure 2. With the new, high-frequency probe the noise is considerably decreased, and rotated horizontal, while the signal is increased. This results in much improved detectability for these defects.

The defect signal sits on a noise ridge that runs the length of the tube. This noise ridge is about 1-volt in amplitude and measures as a deep id defect, on the order of 70 to 100% deep. This ridge makes both the detection and sizing of this defect more difficult. In Figure 5 we show the lissajous of the noise ridge. The signal-to-noise is slightly better for the 400 kHz frequency than the 300 kHz.

There is a signal on the 10 kHz channel that follows the defect. It is not known why the signal is visible at this frequency, although it may be due to a slight ferromagnetism of the crack. In Figure 6 we show the c-scan of the signal that has the same outlines as the crack. This scan also has signal-to-noise problems.

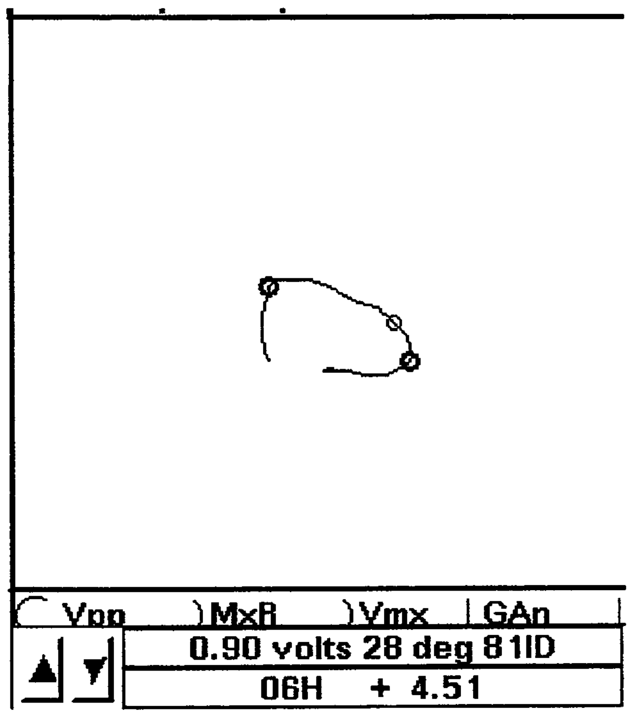

Figure 5 Noise signal that runs the length of the u-bend.

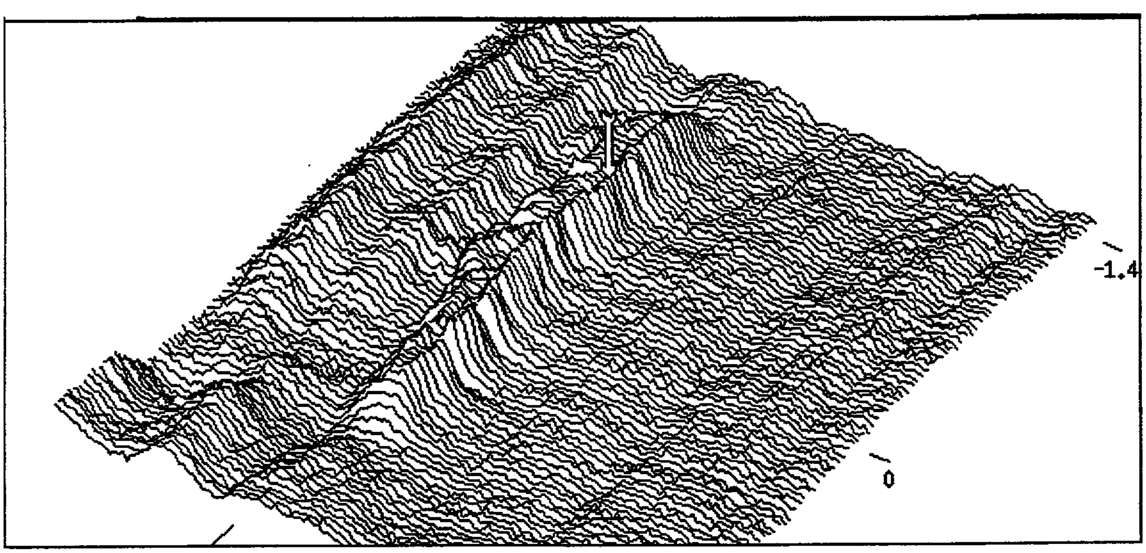

Figure 6 C-scan of the crack at 10 kHz

The indication has been profiled for both frequencies, as is shown in Figure 7. The 400kHz profile is probably slightly more accurate than the 300 kHz profile. Neither is very accurate, and until the defect voltage increases above 1.2-volts, there is considerable error. This can be contrasted to the 0.4-volt threshold for the high-frequency probe. No attempt has been made to

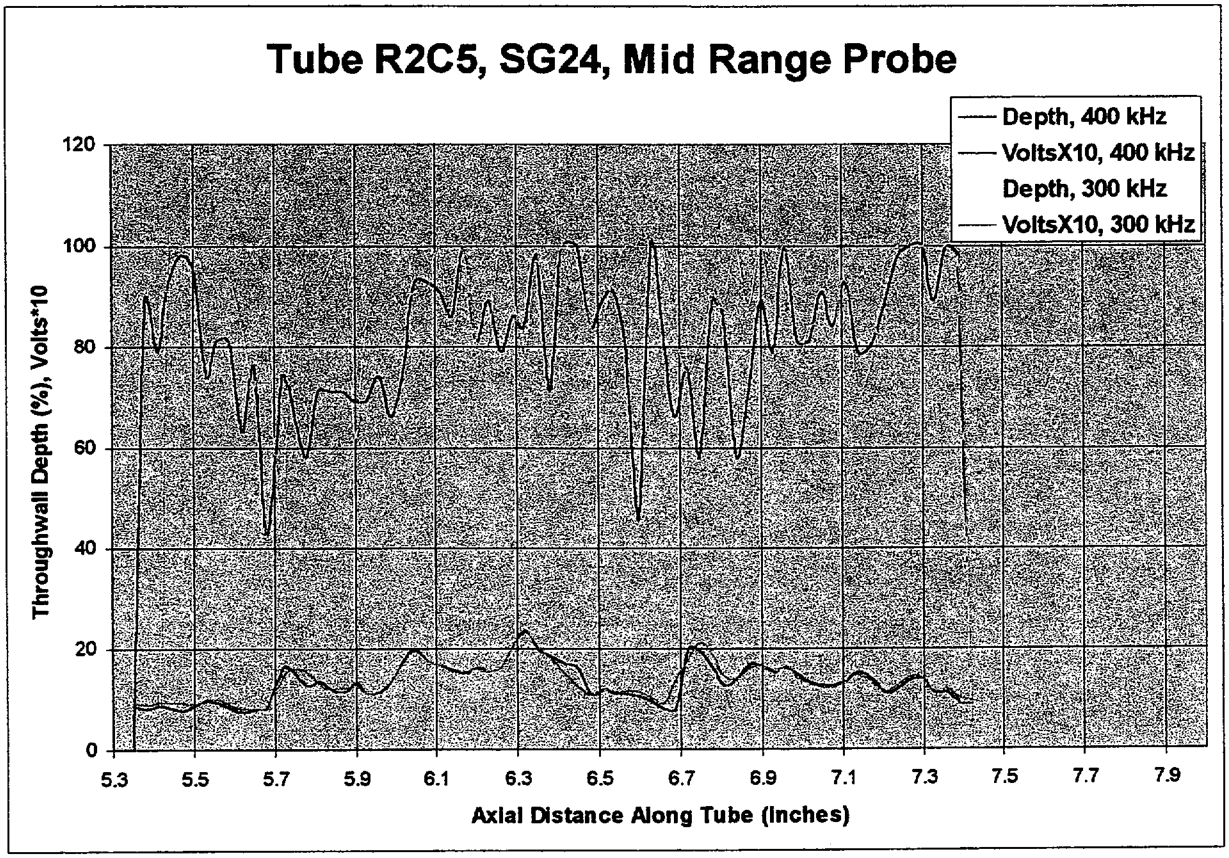

Figure 7 Contour of the crack in tube R2C5 in SG24 using the 1997 data from the mid-range plus-point probe.

adjust these profiles for the end effects of the probe.

Signal Filtering

The Zetec software (and I believe also the Anser software) has the ability to subtract an average signal or a single line signal from both the axial and circumferential c-scan plots. The main use if these "filters" is for cases like this were you need to separate a defect from other naturally occurring signals with relatively constant shapes, such as tube supports or these ridges. Westinghouse discourages the use of filters in general since they throw away some of the signal that may contain a defect. In Figure 8 we show a C-scan of the R2C5 using the circumferential line filter. We are subtracting the signal form a single circumferential line set at the location of the arrow. The defect is easier to see at this location. The signal from the ridges cancels out near the location that we set the line filter, but, due to the variation of the axial ridges with distance along

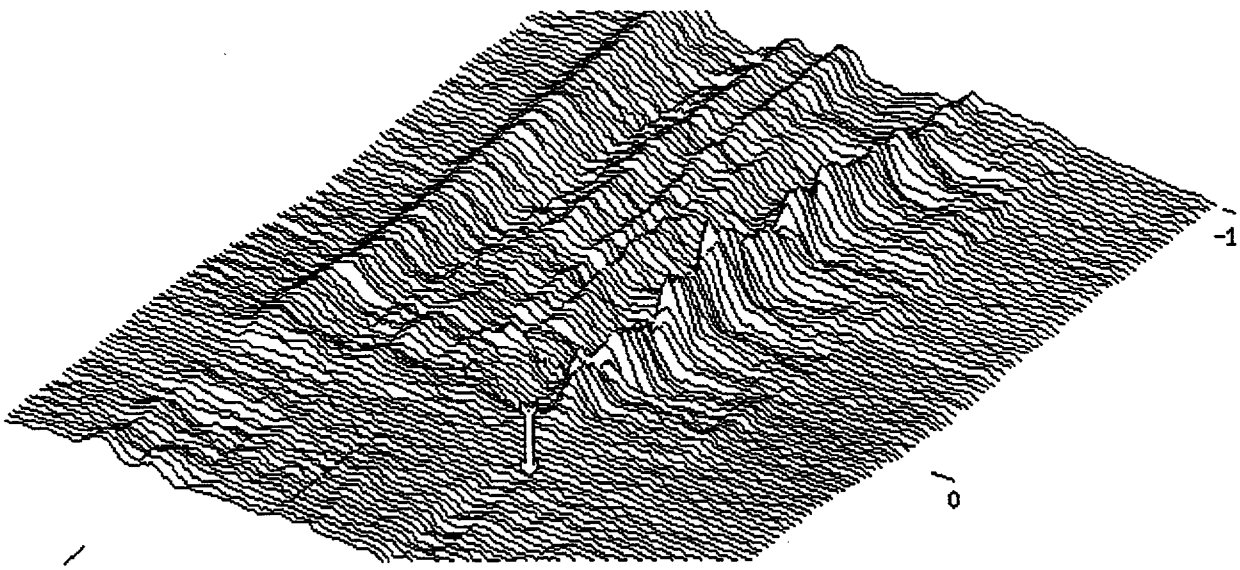

Figure 8 C-scan of tube r2c5 of steam generator 24 using the circumferential line filter.

the tube, it reappears a short distance away. However, the defect signal is displayed in a form easier to recognize. This scan can be compared to the scan in Figure 2 with the line filter off. This method can be used as a tool to help the analyst, but it also does not do as good a job of eliminating the noise signals as the high-frequency probe. It is hard to use the filters and do a profile of the tube since the filters turns off when the next line scan button is pushed.

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Profiles of tube r34c51 of Steam Generator 22

Tube r34c51 was profiled in the sludge region. This tube had two rather long cracks and two shorter cracks. All four were profiled, and are given in the figures below. All of the cracks were just above the tube sheet. The profiles were done using the 200 kHz and the 300 kHz test frequencies of the plus-point probe. Data were taken at 10 kHz, 100 kHz, 200 kHz and 300 kHz with both the plus point and the 0.115-inch diameter pancake coil. The 0.080-inch diameter high-frequency pancake coil was also used at 600 kHz and 300 kHz. The plus-point had the best signal-to-noise ratio for the tubes that I examined in the sludge pile region. The 0.080-inch diameter probe gave a sharp spike-like signal for the cracks. This coil may give better signal-to-noise at 800 kHz, where the noise should be rotated horizontal. Crack 1, as shown in Figure1

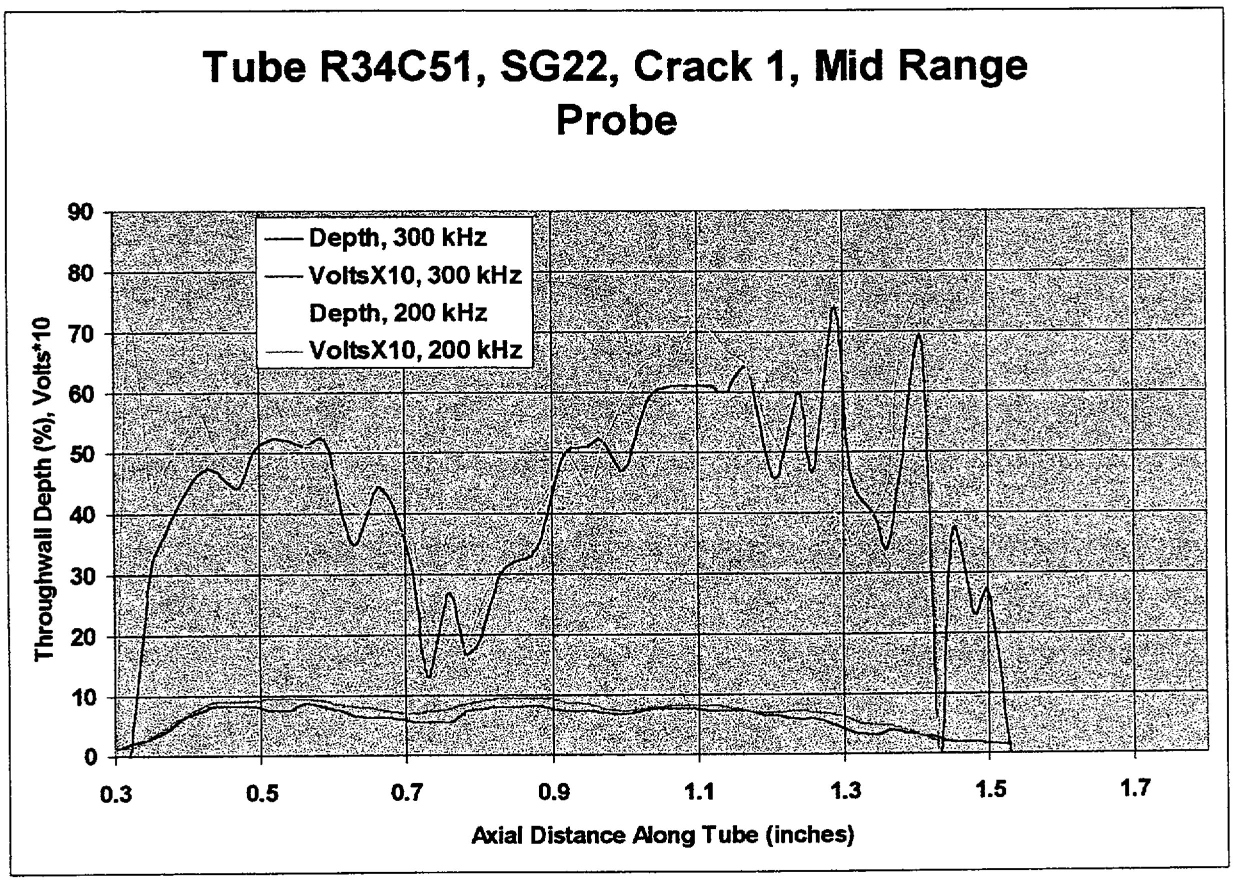

Figure 1 Profile of crack1 in tube R34C51 of steam generator 22.

was one of the larger ones, and had a voltage signal close to one volt. While this crack appeared to grow some in voltage amplitude due to the pressurization, this is not the point were the tube burst.

Crack 2, as shown in Figure 2, is slightly longer and slightly deeper. This is the crack that burst. The voltage amplitude of this crack is about the same, and probably averages less than that of crack one. This demonstrates that voltage is not a good measure of crack size, depth or severity.

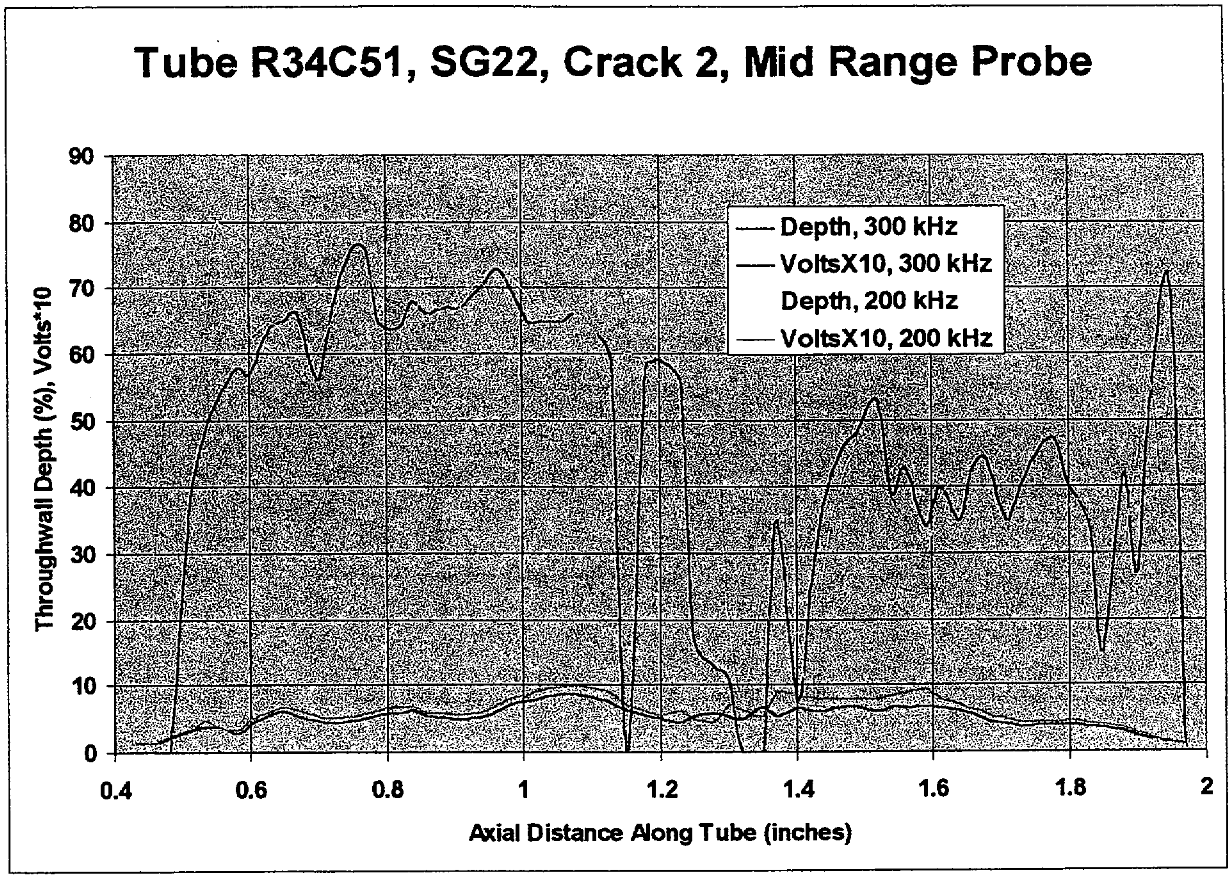

Figure 2 Profile of crack 2 of tube r34c51 in steam generator 22.

Crack 2 appeared to go through wall, and the voltage amplitude increased by a large factor. This tube also had a large voltage increase of a crevice crack due to the pressurization.

In Figure 3 and Figure 4 we show smaller cracks. In the post pressure-test scan these cracks were still visible, but could not be profiled due to the large increase in signal from crack 2. Its signal distorted the phase of the smaller cracks, which were adjacent to it.

The positions of each of the cracks is labeled in the C-scan that is shown in Figure 5. Note the large voltage signal from the cracks in this tube, and the low noise. Other tubes do not have as good a signal-to-noise ratio and are more difficult to inspect in this region.

In Figure 6 we show the post pressurization scan of this tube. The signal form crack 2 is now much greater than the other cracks, indicating that this was the crack where the tube leaked..

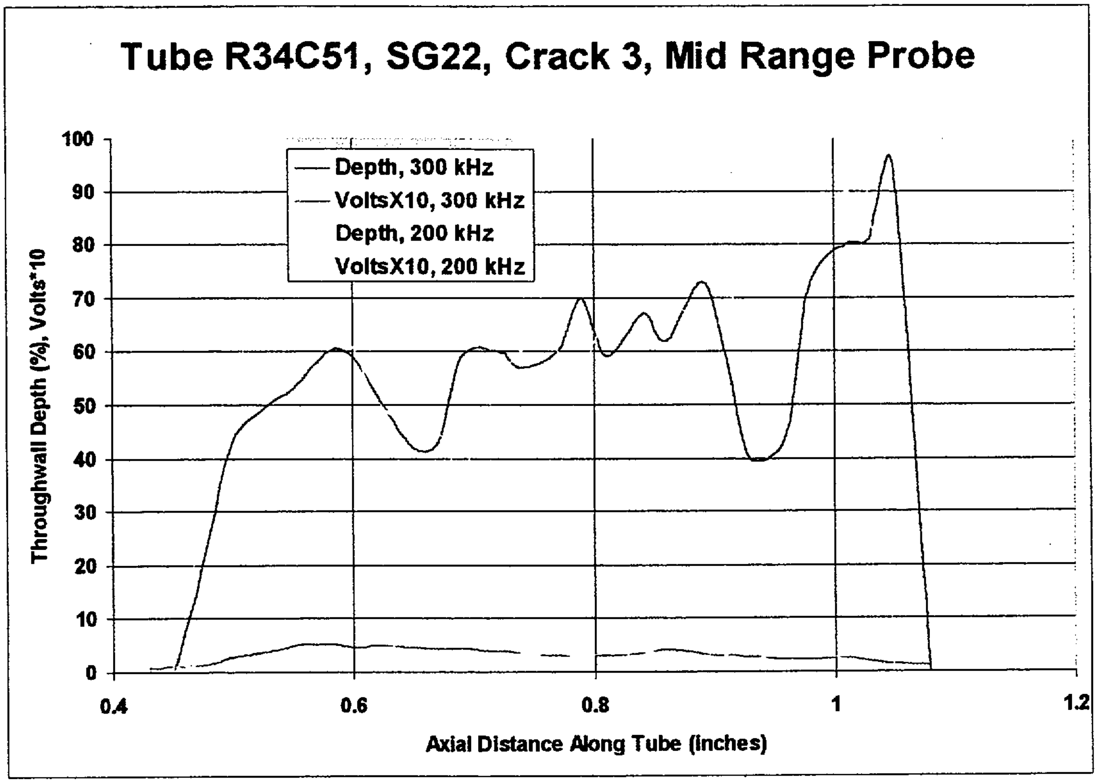

Figure 3 Profile of crack 3 in tube r34c51 of Steam Generator 22.

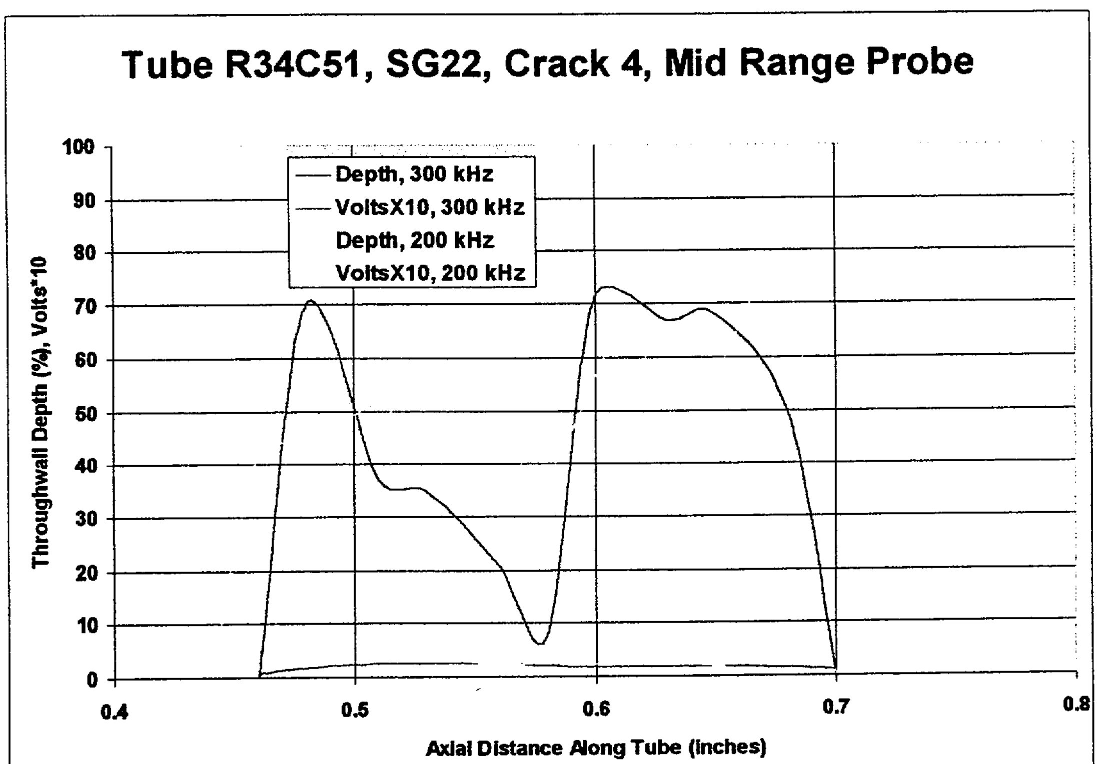

Figure 4 Profile of crack4 in tube r34c51 of Steam Generator 22.

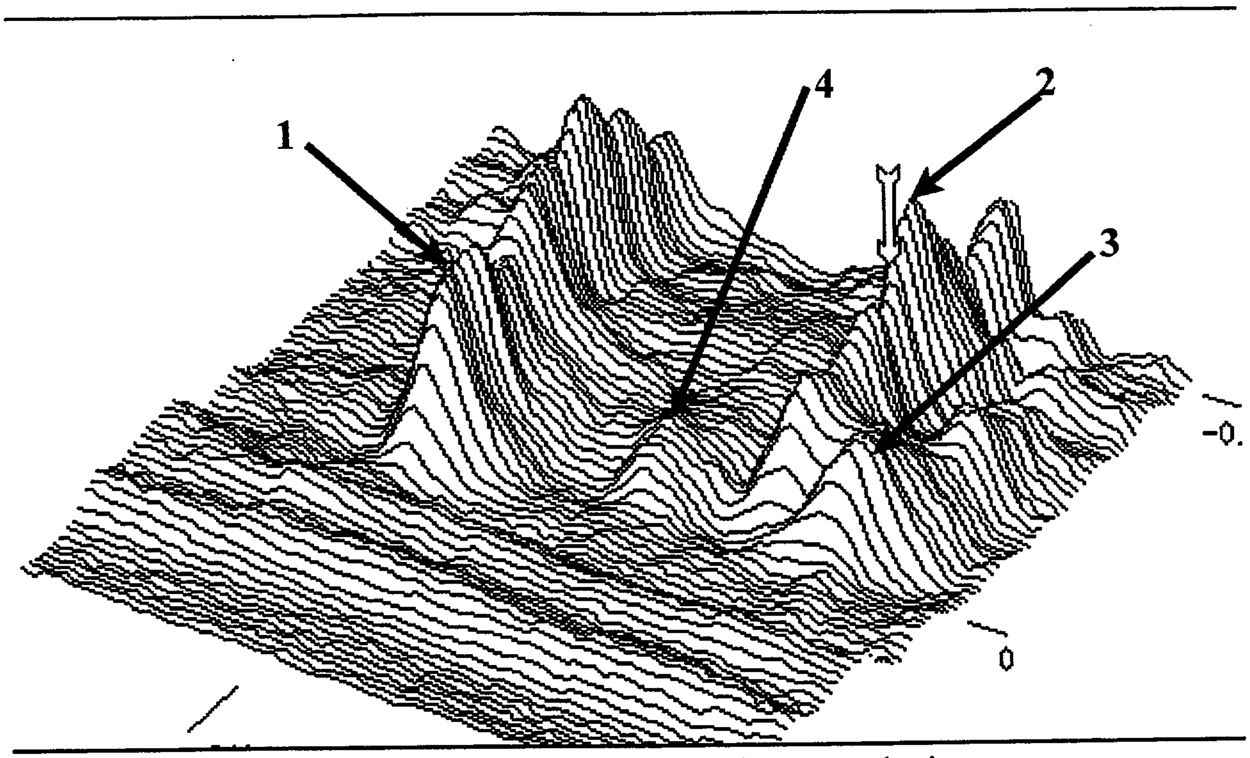

Figure 5 C-scan to tube r34c51 of steam generator 22 before pressurization.

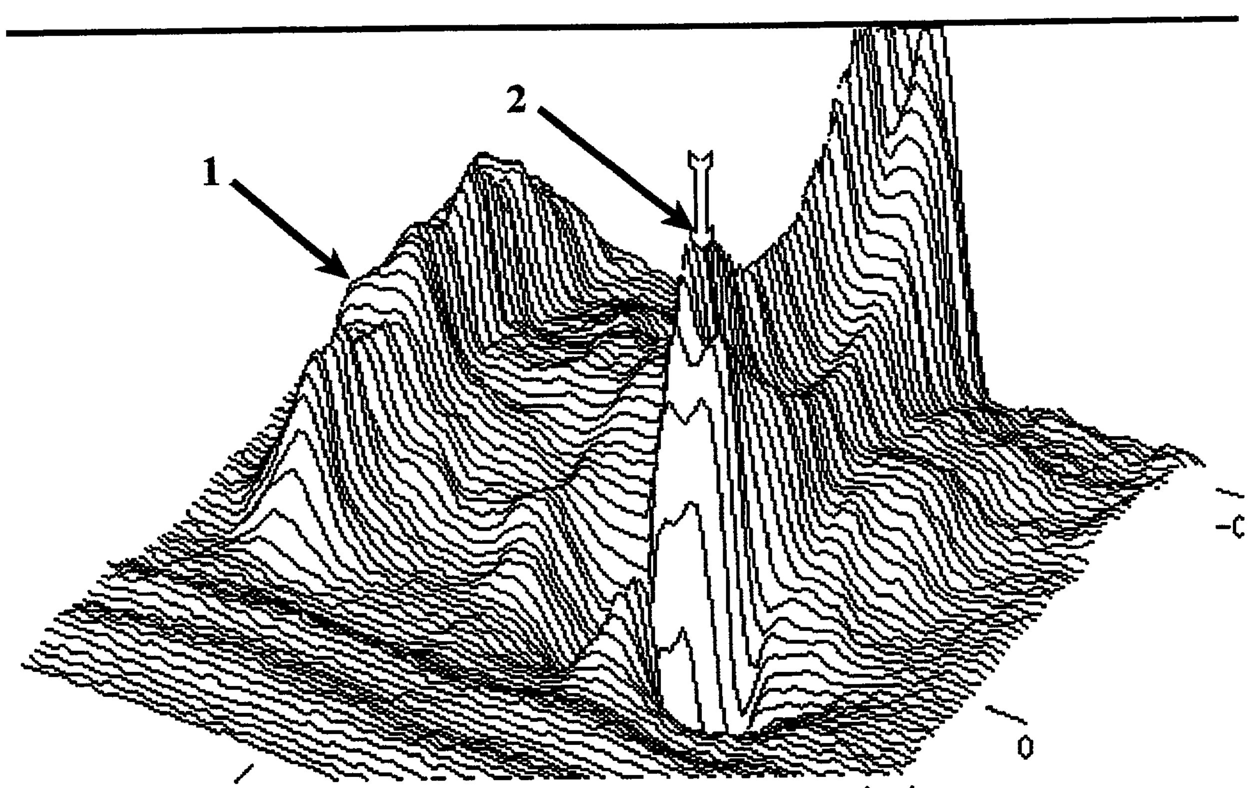

Figure 6 C-scan of tube r34c51 of steam generator 22 after pressurization.