EX6

From: <Doddc[redacted] C. Dodd
To: KP_DO.kp1_po(WLS) W. Schmidt
Date: Tue, May 30, 2000 9:20 AM
Subject: Probe write-up

Wayne:
Here is a compressed file with the probes write-up in it. Execute it to uncompress it. It is in WordPerfect format. Let me know if I can be of any more help.
Caius

Need copy of the write up

Information in this record was deleted in accordance with the Freedom of Information Act, exemptions 6
FOIA- 2001-0256

6/5

ITEM

10

Review of Eddy-Current Probes

During the past year, new problems have emerged in the nation's steam generators. In order to address these problems, a number of new probes (and innovations on old probes) have been developed. The purpose of this write-up is to review these probes so the reader will have some idea of what they are and how they work. The probes include the Cecco 3 and Cecco 5 probes, the Zetec axial and circumferential probes, the Zetec Plus-Point probe and the high frequency probe. Additional analyst training and changes in the prresent procedures and guidelines are needed with these new probes.

Cecco Probes

To address the potential for degradation associated with sleeved tubes, Westinghouse is proposing to use probes developed at the Chalk River Nuclear Laboratories in Canada by Mr. Val Cecco and his associates. We were given an explanation of the Cecco 3 and Cecco 5 probes by Gary Pierini of Westinghouse, and furnished additional information by Val Cecco. In Figure 1 we show the coil arrangement for the Cecco 3 probe. There are two bands of transmitter and receiver coils at different axial locations around the circumference of the tube. The receiver coil pairs are connected in opposition, so that the sum of the signal received is the difference between

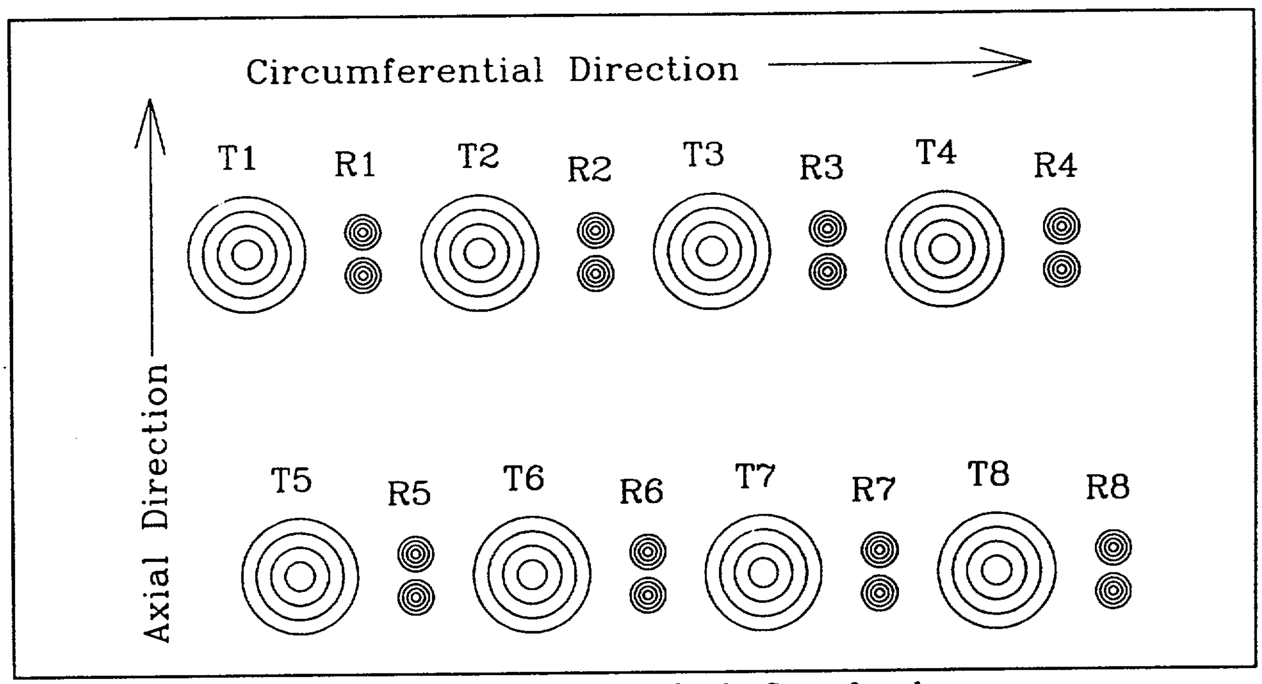

Figure 1 Coil layout around circumference of tube for the Cecco 3 probe

that detected by each coil. The even numbered transmitter coils and the odd numbered transmitter coils are driven at alternate times, permitting each receiver coil pair to alternately receive a signal from the adjacent transmit coil on the left and then the transmit coil on the right.

For transmit-receive coils, the signal produced by a defect is the product of the field produced by a unit current in each coil at a point (defect sensitivity factor) times the defect size, shape and orientation factor. The region of maximum sensitivity for the transmit-receive coils is shown in Figure 2, along with the direction of current flow of the driver coil. The region of greatest eddy-current flow is under the driver coil and the field and current flow fall off as the distance

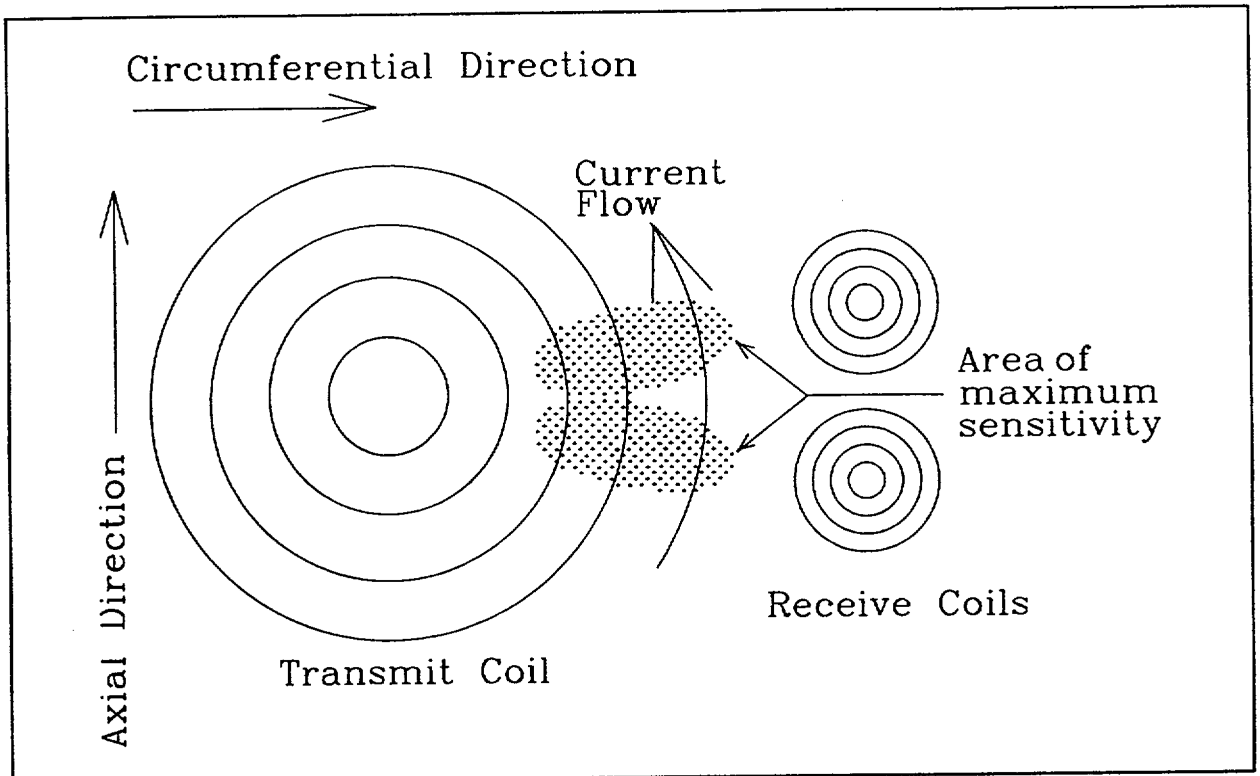

Figure 2 Cecco 3 probe, showing the position of the transmitter coil and the differential receiver coils

from the driver coil increases. Since the defect signal produced by the transmit-receive coil is the product of the fields between the two coils, the region of maximum sensitivity is between the transmit and receive coils. The principle of reciprocity states that the mutual coupling between the two coils is independent of which coil is the driver and which coil is the receiver. However, the driver coil usually has a larger current carrying capacity, and while two banks of transmitter coils are connected in parallel, the receiver coil pairs are connected to individual circuits. Only the driver coil is producing a current that will interact with the defect. Therefore, if the current induced by the driver coil is in a direction so that the current is interrupted by the defect, a signal will be produced by that defect; but if the major defect dimensions are parallel to the current flow, the defect will not be detected. As can be seen from Figure 2, the direction of the current is mostly in the axial direction. As a result, a circumferential defect will interrupt more of the current flow than an axial defect. For this reason, the Cecco 3 does a good job of detecting circumferential defects but a poor job of detecting axial defects. Also, due to the differential nature of the receive coils and the rapid dimensional variation of a circumferential defect in the axial direction, the circumferential defect signal is more pronounced as the tube is scanned axially. It should be noted that each transmit coil in Figure 1 will produce an area of sensitivity with the receive coils on each side of the drive coils, so that 8 areas of detectability are produced in each of the alternate time slots. Therefore with this probe, there are 16 areas of defect detectablilty around the circumference of the tube. The number of transmit coils used in a probe depends on the tube and probe diameter.

The Cecco 5 probe is similar to the Cecco 3 probe, except for the placement of the receive coils, as shown in Figure 3. The receive coils are moved so that the current flow from the transmit coil is at an angle of 45 degrees to the tube axis. Therefore, both axial and circumferential cracks will interrupt the current flow and a defect signal will be produced by both. The Cecco 5 will detect both axial and circumferential cracks, but the sensitivity to circumferential cracks was stated by

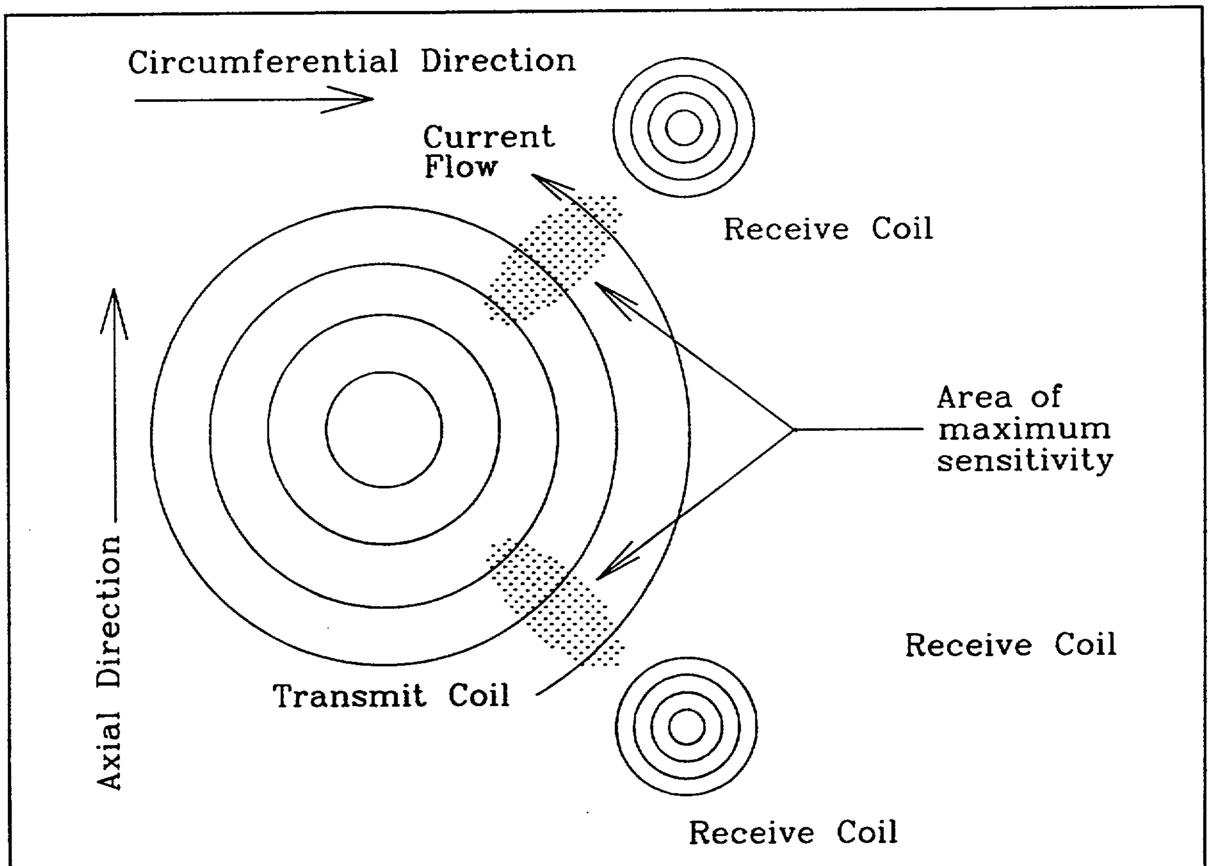

Figure 3 Cecco 5 probe, showing the placement of the transmit and receiver coils

Gary Pierini to be about 10% to 15% less than the Cecco 3 probe. The signal for circumferential defects from a Cecco 5 probe should be reduced since the angle between the major crack dimension and the current flow is less than 90 degrees and the receive coils are further apart and therefore produce a less clear differential signal. While the Cecco 5 probe easily detected axial EDM notches, an axial defect with slowly varying dimensions in the axial direction, such as some long cracks observed in the free span, would be difficult to detect. Axial cracks less than

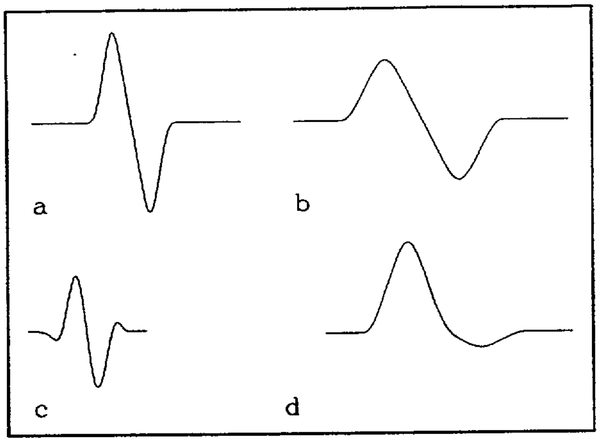

Figure 4 a) Defect signal amplitude plotted against distance for the Cecco 3 probe, Circ. defect

b) Defect signal amplitude plotted against distance for the Cecco 5 probe, Circ. defect

c) Defect signal amplitude plotted against distance for the Cecco 5 probe, Axial defect

d) Defect signal amplitude plotted against distance for the Cecco 5 probe, 45 deg. defect

25 mm long, as expected in the sleeves, should be easy to detect.

In Figure 4 we show the types of signals that would be produced by different defects as they are scanned with the different types of probes. The Cecco 3 probe would produce a very sharp signal for a circumferential defect, as shown in Figure 4a, while the Cecco 5 would produce a more gradual signal, as shown in Figure 4b. The Cecco 5 will also detect axial notches as shown in Figure 4c. For a defect at a 45 degree angle, the Cecco 5 would detect it but the signal would be non-symmetrical as shown in Figure 4d. These drawings are based on computations, but they were reported by Val Cecco to agree closely with measurements.

All of the scans from Figure 4 would produce some type of lissajous signal, (similar to those produced by a differential bobbin probe) as shown in Figure 5, when the real impedance is plotted against the imaginary impedance. In Figure 5a we show a the signal produced by a circumferential defect when scanned with a Cecco 3 probe. In Figure 5b we show the scan of a circumferential defect for the Cecco 5 probe. In Figure 5c we show the scan of an axial defect for a Cecco 5 probe and in Figure 5d we show the scan of a 45 degree defect with the Cecco 5 probe.

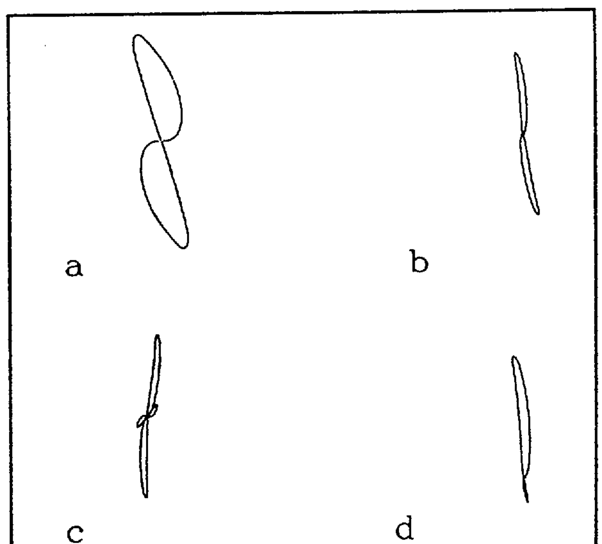

Figure 5 a) Circumferential defect signal for a Cecco 3 probe

b)Circumferential defect signal for a Cecco 5 probe

c)Axial defect signal for a Cecco 5 probe

d)45 degree defect signal for a Cecco 5 probe

In addition to the differential signals of the receive coils, a differential signal can be developed around the circumference of the tube by taking the difference of the signal produced by the individual channels. Since this is done in software, it can be used to supplement the information in the raw channels and increase the detectability of axial cracks. Circumferential cracks with dimensions that vary slowly around the tube may be missed using this technique; therefore, it should be used only as a supplement to the raw channels.

A number of scans on sleeved tubing using both the Cecco 3 and the Cecco 5 probes were reviewed, and there was very little difference for the circumferential notch sensitivity. The notches were on the outer surface of the parent tubing where the sensitivity will be considerably reduced from normal eddy-current tubing inspections. Both probes were able to detect the 52% circumferential defects in the standards, while the Cecco 3 could not detect the axial defects. We were given a packet of eddy-current scans for both probes, showing both EDM notches and cracks in welded sleeves (as used at Doel 4) and in roll transition sleeves (as used at Point Beach or Kewaunee). In Figure 6 we show a scan made by the Cecco 5 probe of an axial SCC defect approximately 50% deep and 13 mm long on the outer surface of an expanded sleeve.

Chalk River performed a systematic mapping of the region of sensitivity for the Cecco 5 probe using a 1.6 mm dia. hole, and Westinghouse did a statistical "qualification" using three scans with a random orientation of the probes with axial EDM notches. A systematic mapping of the probe with EDM notches (similar to what was done at Chalk River with the holes) is be better since it insures that there are no "dead spots" in the probe. The Cecco probe data that we have reviewed were for standard tubes outside the generator, and the quality of data in the generator, where deposits, dents, dings, and other noise signals may be present, will probably not be as good.

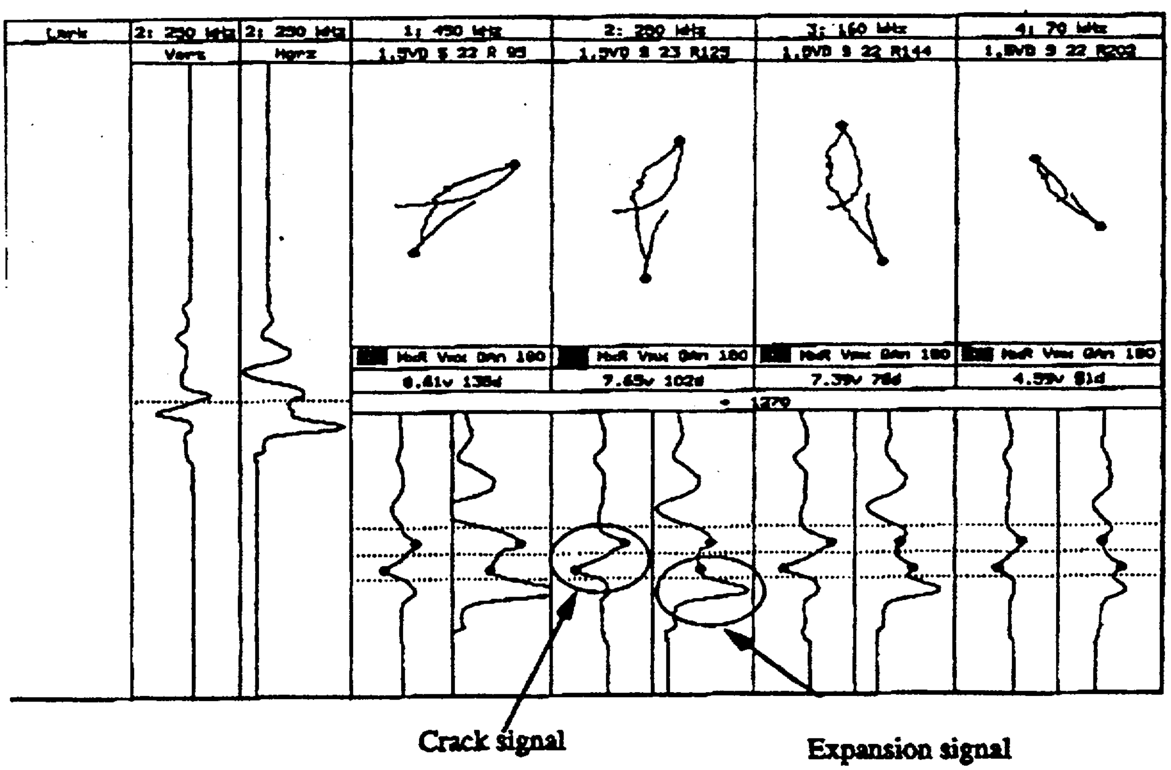

Figure 6 Cecco 5 signals from a laboratory induced stress corrosion crack

Directional Probes

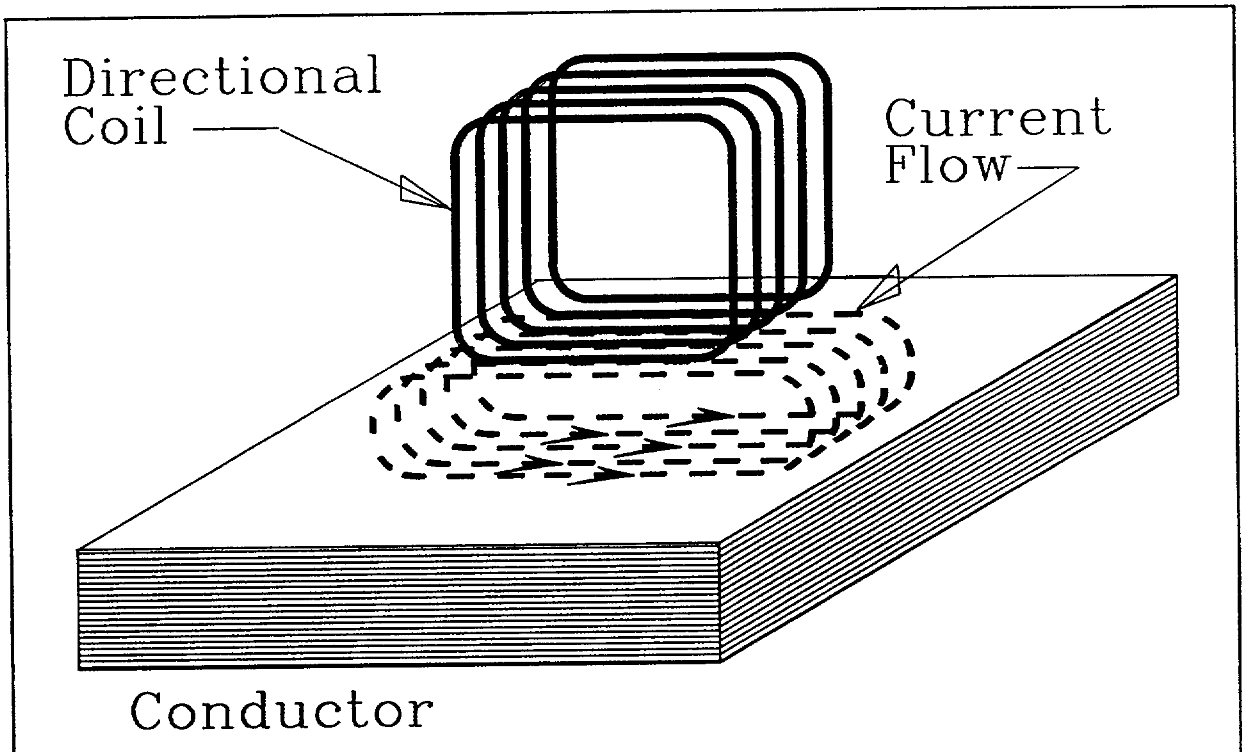

Figure 7 Directional pancake probe

Specially designed eddy-current tests can classify defects as axial cracks, circumferential cracks and volumetric flaws. At present, this is best accomplished by directional pancake coils, as shown in Figure 7. These probes will induce current in only one direction, which is a compressed mirror image of the current in the coils. If the defect is not in the direction which interrupts the eddy-current flow (parallel to the defect direction rather than perpendicular to the current flow), then that particular coil in the pancake probe does not see the defect. These directional probes are used only in the Zetec 3-coil probe, the Zetec I-coil probe, and the Zetec Plus-Point probe. In all three probes, there are two directional coils, one in the axial direction and one in the circumferential direction. These probes will classify pits, wastage, fretting, and volumetric IGA as volumetric defects. Unfortunately, they also will classify cracks at a 45 degree angle to the tube axis and a network (lattice) of cracks that go in both the axial and circumferential directions as volumetric. If cracks had perfect orientation along their length and had no width, and the coils were constructed perfectly, then there would be no signal from a circumferential crack with the axially sensitive coil, and vice versa for the circumferentially sensitive coil and the axially oriented crack. These probes have been tested on both EDM notches and actual cracks. Usually the axially sensitive coil will produce less of a signal on the actual circumferential crack than on the circumferential EDM notch, due to the fact that the crack usually has less of an axial extent than the EDM notch has. The directional probes are much better at discriminating between axial and circumferential cracks than a regular pancake probe, due to the limited resolution of the pancake probe. In practice, if one coil has a twice or more the signal of the other, we can conclude that there are cracks in the direction indicated by the coil with the larger signal. Often there are deposits present or geometrical dimension variations that will produce signals on both coils, which will confuse the readings if these artifacts are not mixed out.

The bobbin coil is not sensitive to circumferential cracks due to the fact that its current flow is entirely in the circumferential direction. Westinghouse argues that if the bobbin coil does not detect an indication but the pancake coil does, the indication must be circumferential. While this is true, it does not give as quantitative a measure of the relative sizes of the circumferential and axial signals as the directional pancake coils do. Since, as discussed in the preceding paragraph, circumferential cracks may have some axial signal due to branching and deposits, it is much harder to get a quantitative measure of the relative axial and circumferential components when different coil types are used.

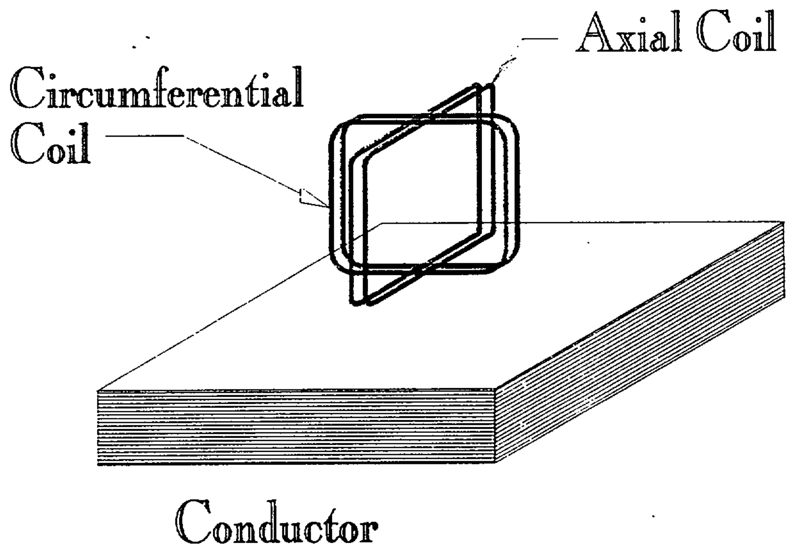

Figure 8 Plus Point probe

The directional coils in the Zetec regular three-coil probe and the I-probe are each mounted in a separate shoe that rides the inner surface of the tube to minimize lift-off. The Plus Point probe consists of two directional coils wound at 90 degrees to each other, as shown in Figure 8, and mounted together on the same shoe. The turns of the two coils are interleaved so that both are effectively the same distance from the surface of the conductor. The coils are connected in a bridge, as shown in Figure 9, and the difference between the two signals is amplified. Large geometry artifacts, such as tube wall thickness, lift-off and many large od deposits tend to cancel out. The current flow in the conductor is a compressed image of the current flowing in the coils, except at the point the coils cross.

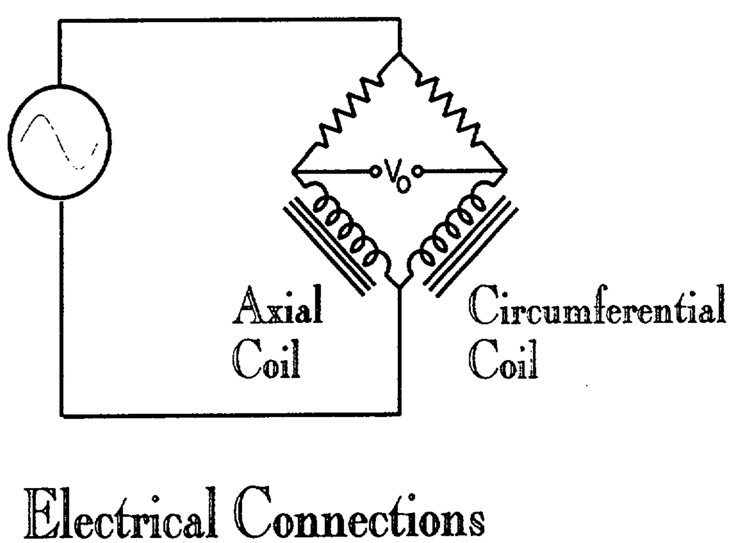

Figure 9 Difference signal from axial and circumferential coils are amplified

Due to the difference in direction of the current in the two coils, axial cracks and circumferential cracks do not cancel out. The cancellation of these large signals allows a better signal to noise ratio in many instances. Therefore, a higher gain can be used and many types of defects that were previously hidden in the noise are now detected. Zetec has performed qualification studies with this probe for sleeve inspection, roll transition inspection, severe denting, and u-bend inspection. Inspections in actual steam generators have also been performed for sleeves, roll transitions, and u-bends. The plus point inspection results were much better than normal pancake coil inspection for the sleeves and roll transitions, and somewhat better for the u-bends.

High Frequency Probe

Most of the defects encountered in eddy-current inspections are on the outer surface of the tubing and our tests have been designed over the years to maximize the detection and characterization of these defects. However, defects on the inner surface of the tubing are much easier to detect and size, and these defects have been imaged with a fair degree of success. The main change is to use a higher operating frequency and smaller coils. A modification was made to the shielded pancake probe for higher frequency operation. In general, the number of turns needs to be decreased and the cable capacitance reduced as much as possible. These coils will not operate well at low frequencies, but this is not needed for the test. When tested at Main Yankee, these coils worked even better than the plus point probe. The high frequency coils are insensitive to things on the tube outer surface, such as deposits and the tube sheet. The coils also had very small lift-off signals, although the reason for this is not apparent. A "super probe", consisting of three shoes, one with a regular pancake probe, one with a plus point probe, and one with a high-frequency shielded pancake probe were tested. This seems to be the probe of choice when inspecting the roll transition regions. The "super probe" also demonstrated the ability to distinguish between tubes with id and od cracking at the top of the tube sheet at Calvert Cliffs.

Calibration Standard

The performance of these probes will not be realized unless calibration standards that accurately simulate the range of expected defects are used. This means a series of axial and/or circumferential notches, on both the tube od and id must be used to accurately calibrate these probes. The ASME Section XI standard with flat bottomed holes is a very poor representation of cracks, particularly for directional probes. In addition, the cable between the instrument and the probe should be as short as reasonable and should be low capacitance, low noise and low loss.

Additional Analyst Training

The analysts should have additional training about the design of these new probes and their use. The calibration and use of these probes should also be covered in the data analyst guidelines.

Summary

In response to new degradation in the steam generators, a number of new probe developments have been made. The Cecco array probes have the potential of high speed inspections. The Plus Point probe has significantly increased our ability to detect small defects in the roll transition region, at tube supports and with severe dents. A high frequency probe was developed for inspection of id cracking. Additional analyst training on these probes are necessary, and EDM notch standards are needed to inspection for cracks. Qualification studies for probes should include od artifacts such as deposits of copper and magnetite as well as tube supports and straps.

Due to the increased sensitivity of the new probes, some form of alternate repair criteria should be implemented. To support this criteria, the length and depth of the defects should be measured, preferably before metallographic examinations are performed on pulled tubes.