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EDDY CURRENT AND ULTRASONIC FUEL CHANNEL INSPECTION AT KARACHI NUCLEAR POWER PLANT

W. R. Mayo
Atomic Energy of Canada Limited
Chalk River Laboratories
Chalk River, ON K0J 1J0

and

Muhammad Mansur Alam (PAEC)

ABSTRACT

In November of 1993 an in-service inspection was performed on eight fuel channels in the Karachi Nuclear Power Plant (KANUPP) reactor. The workscope included ultrasonic and eddy current volumetric examinations, and eddy current measurement of pressure-to-calandria tube gap.

This paper briefly discusses the planning strategy of the ultrasonic and eddy current examinations, and describes the equipment developed to meet the requirements, followed by details of the actual channel inspection campaign.

The presented nondestructive examinations assisted in determining fitness for service of KANUPP reactor channels in general, and confirmed that the problems associated with channel G12 were not generic in nature.

1. INTRODUCTION

The KANUPP reactor core consists of 208 fuel channels, each of which comprises two concentric horizontal tubes with end fittings at each end. These tubes i.e., the pressure tube (heat treated, Zr-2.5%Nb; inside diameter; 82.9 mm; thickness: 4.38 mm) and the calandria tube (Zr-2) are separated (diametrical gap: 9.2 mm) by two tight fitted spacers called garter springs (Fig. 1). The fuel channel integrity depends on the pressure tube, as it forms the main pressure boundary. During reactor operation it experiences severe stress & temperature variations in a high thermal and fast neutron flux environment. In addition to this, phenomena such as debris frets, abnormal fuel supports, localized electrical resistivity variation, fuelling tracks with and without magnetic deposits, and material lap flaws may occur.

The reactor channel G12 at KANUPP was discovered sagged in 1987, to the extent that its on-power fuelling was no longer possible. This and another channel F15, which too was found somewhat retracted, operated without any fuel subsequently. The cause of a phenomenally large sag of over 40 mm in the case of G12 was suspected, in the very initial stages, to be due to restriction in the horizontal movement of the tube at the free end. The ASSETT mission of the IAEA recommended in 1989 the removal of channel G12 and inspection of a few additional channels, including F15, to ascertain the cause of retraction and establish beyond reasonable doubt whether or not the problem was generic in nature.

An in-service inspection of eight fuel channels was subsequently carried out in 1993 November as part of an assessment of KANUPP fuel channel fitness for service. The entire scope of the site work included:

1) Ultrasonic and Eddy Current Volumetric (Flaw Detection) Examinations,
2) Eddy Current Measurement of Pressure-to-Calandria Tube Gap,
3) Dimensional Gauging,
4) Material Sampling,
5) Removal of channel G12, 6) Post Removal Photography and Visual Examination, and
7) Post Removal Sample Cutting for return shipment to Chalk River Laboratories, where metallurgical examinations took place.

This paper concentrates on the flaw detection examinations and pressure-to-calandria tube gap measurements, which provide important parameters for the reactor fuel channel integrity assessment.

2. SELECTION OF CHANNELS FOR INSPECTION

The CSA standard (CAN3-N285.4-M83) minimum requirement is to inspect a total of five channels, four in the high flux and one in the low flux region respectively [1]. Eight channels were chosen for the inspection. The increased number of channels from five to eight was aimed at acquiring detailed information for the integrity assessment, since it was the first KANUPP reactor channel inspection in its (over) two decades of operation.

3. INSPECTION PLAN

The plan called for ultrasonic flaw detection in channels F15 and G12. Providing that the ultrasonic examination of F15 showed no generic outside surface phenomena of concern, the remaining six channels were to be examined by eddy current flaw detection. Channel G-12 was also scheduled for ultrasonic examination because of its seized condition. However, due to its unique nature, the results of ultrasonics in this channel were not to be used in the decision to proceed with eddy current or ultrasonic flaw detection in the remaining six. All eight channels were to be profiled for pressure-to-calandria tube gap, since the garter springs without girdle wires in the KANUPP design are not detectable using the standard eddy current methods, and hence no dedicated spacer detection method was available.

The plan was modified during on-site actual inspection, due to the occurrence of anomalous gap profiling results in channel J10, requiring ultrasonic flaw detection to be carried out in that channel as well as eddy current. Thus, the actual examinations performed in the eight channels are summarized in Table 1.

Table 1
1993 KANUPP Ultrasonic, Eddy Current, and Gap Examinations

Channel	UT	ET	Gap
F-15	X		X
G-12	X		X
F-06		X	X
G-08		X	X
J-10	X	X	X
G-09		X	X
K-09		X	X
N-03		X	X

Notes :
i. "X" denotes this type of examination was performed.
ii. The actual order of the sequence of events is not as suggested by the table.

4. PREPARATORY WORK

The on-site inspection of fuel channels required extensive preparatory work. This was because KANUPP pressure tubes are of smaller diameter than the 103 mm diameter tubes for which AECL-CRL equipment was designed. Therefore necessary equipment required modification involving re-design and fabrication.

It should be noted that AECL-CRL adopted the "dry technique" of examination, in which inspection is carried out with drained channels, as opposed to the "wet technique", in which channels to be inspected remain fully flooded with D_20 (CIGAR system). A brief description of work done at AECL-CRL and KANUPP is given below:

4.1 At AECL-CRL

1. Re-design, development and fabrication of volumetric inspection heads for ultrasonic, eddy current and gap measurement.
2. Design and fabrication of calibration tubes for volumetric and gap measurements.
3. Modification of the delivery unit i.e., STEM (Storable Tubular Extendible member). STEM units were chosen, due to their simplicity and size, to deliver the various inspection heads in the channels.
4. Improvement in software for data acquisition and display.
5. Fabrication and assembly of a full-size single channel mockup simulating G12, for proof testing equipment.
6. Deployment of a multichannel ultrasonic instrument (USIP-20H) for inspection.

After completion of the above modifications, the complete system was satisfactorily tested on the mockup before dispatching it to KANUPP.

4.2 At KANUPP

1. A single channel mock-up was installed to check the equipment and training of KANUPP personnel prior to actual inspection work.
2. The reactor fuel channels were defuelled, drained and swabbed prior to installation of inspection sleeves. These sleeves were provided to compensate the dimensional difference between pressure tube and end fitting inside diameter, so that inspection heads could move easily. The inlet side sleeve design had the provision of keeping the latch finger in its open position.

3. Inspection platforms were provided on both reactor faces to position test equipment and allow maneuverability of inspection personnel. A control room was also established for data acquisition.

5. EXAMINATION

Ultrasonic flaw detection was performed using four-direction angle beam (approximately 45^0) 10 MHz shear wave examination, and 15 MHz normal beam. The head is depicted in Fig. 2. Coupling was maintained by low pressure pumping of water (D_2O) to the transducer insert, where a pocket of water was maintained by the spring loading of the insert against the tube wall. This system is usually referred to as a "bubbler". Run-off water was collected by a drip spout and returned to the pump reservoir periodically. At the time this system was designed, space limitations necessitated the use of 6 mm diameter (active element) ultrasonic transducers. Other than this, the transducer specifications were the same as those used in Ontario Hydro's CIGAR system. Sensitivity would thus be expected to be comparable to that of CIGAR, with some minor relative decrease in signal-to-noise. Full coverage of the tube volume required a spiral scan pitch of 1 mm. It took about 6 hours to scan a channel.

Eddy current flaw detection was performed using a Ghent 1 surface probe at 50 kHz. This type of differential probe exhibits high sensitivity to shallow surface breaking flaws in pressure tubes. The head is depicted in Fig. 2, and consisted of a simple rotating section with spring-loaded probe. The central anti-wear tip of the probe was sapphire, which eliminates any requirement for adjustment of instrument settings due to "lift-off" variation as the scans progress. No couplant is required for eddy current examination, which greatly simplifies this type of head in general. For re-examination of investigatable indications, the central coil of the Ghent probe was used, with a built-in isolated reference coil, in absolute mode. No change of probe was thereby required. Under favourable conditions this type of flaw detection has been demonstrated to detect flaws of depth 0.10 mm and length less than 6 mm. Under typical KANUPP reactor conditions it was however believed that the limit of detectability was closer to 0.15 mm deep and less than 6 mm long. Full tube coverage, with some overlap, required a scan pitch of 2 mm. It took about 50 minutes to scan a channel.

The gap measurement was performed using a large diameter send-receive eddy current device. Testing at CRL before examination at KANUPP, using a representative sample of pressure tube, indicated sufficiently low sensitivity to wall thickness variation that wall thickness compensation was not required for the send-receive configuration used. The head, depicted in Fig. 2, was run along the channel to plot axial profiles at the bottom and one side of the channel, and rotated at five equi-spaced locations to plot circumferential profiles[1]. For each type of profile, gap was typically sampled at every millimetre of axial (circumferential) travel. About half an hour was required to scan a channel.

Set-up of the equipment is shown in Fig. 2.

6. PERFORMANCE OF EQUIPMENT

Ultrasonic signal-to-noise was judged satisfactory. This can be seen in the signals from the calibration notches and was evident in the data during scanning (Fig. 3). A strip chart display of the digitized data was generated as scanning took place. After scanning of a channel was complete, an "off-line" C-scan of the data could be generated (Fig. 4). This tended to greatly aid the detection of low level signals that might be lost in the noise of the compacted strip-chart, and allowed inspectors to verify whether echoes detected on successive rotations represented a flaw of axial extent or were simply the result of random reflections. The presence of serious flaws is not therefore expected to have gone undetected.

The eddy current equipment was quite satisfactory, and the STEM units worked very well with the eddy current flaw detection system. Reference signals from 0.15 mm deep (typ.) EDM reference notches generally showed a signal-to-noise ratio of about 3 (Fig. 3). As with ultrasonics, data could be displayed in an off-line C-scan format, which aids detection and characterization. An X-Y (impedance plane) re-display capability also enhanced the ability to characterize indications from the eddy current data (Fig. 4).

Equipment for gap measurement functioned near flawlessly, and data display was satisfied by the simple generation of strip charts for axial and circumferential scans. The greatest issue in gap measurement performance involved the discovery of

[1] CAN3-N285.4-M83 has no requirements for pressure-to-calandria tube gap measurement. These are considered reasonable choices.

anomalies in the data. Examples are shown in Fig. 5. These were areas where the gap measurement data could not be reconciled with expected results based on other sources of information.

STEM unit performance was satisfactory, however one or two noteworthy problem areas were encountered during the inspection, as follows :

(1) Damage of STEM unit elements:

In channel G12 the excessive force required due to abnormally high sag caused buckling of the STEM element, which was replaced. The remaining acquisition of data was completed successfully by accessing the channel from the other end.

(2) Failure of bubbler system:

The hydraulic pump providing water couplant to the ultrasonic probes failed. This piston pump failed due to a knuckle-joint dislocation in its housing. The knuckle-joint was coupled to a reciprocating piston on one side and a motor gearbox on the other. The loose viton housing was repaired. Also, on one occasion the ultrasonic head had to be dismantled to remove fibrous material that clogged the couplant supply tube. (Improved filtration would correct this problem in the future.)

7. RESULTS

1. Ultrasonic and eddy current flaw detection of KANUPP channels showed them in general to be in good condition. Features that were found in the channels were representative of normal operational wear in CANDU reactors. Channel G12 was however an exception to this statement, due to its locked end fitting. This channel was in contact in the central region during hot conditioning of reactor operation, which became evident after channel removal and subsequent underwater visual inspection. This was not however a generic case.

2. The gap measurement using eddy current gave anomalous results. For example, in J10 the measurement suggested the pressure tube might be near contact with the calandria tube, in the south channel end, which was not supported by ultrasonic inspection. Again, in the same channel the gap was measured to be highly nonuniform at a distance of 300 mm from the end fitting, which is difficult to accept since the tubes are expected to be concentric at this location.

3. Based on the ultrasonic flaw detection, gap profiling, and dimensional gauging results, channel F15 was considered adequate for normal operation and accordingly returned to service.

8. CONCLUSIONS

In view of the scope of work involved in these examinations, the overall result was quite satisfactory in accordance with the CSA requirement. There is room for improvement in subsequent inspections in the following areas using the dry-technique :

1. The delivery system requires improvement to cope with abnormal channel sag, and an automated couplant collection system is necessary.

2. The accuracy of the gap measurement system may be increased by compensating the effects of wall thickness variation. This is based upon Ontario Hydro's SLAR and CIGAR experience, where a dramatic effect on eddy current signal is seen as a result of wall thickness variation, to the extent of 50% gap equivalent [2]. (Note however that the KANUPP 93 gap probe is different than those used on SLAR and CIGAR, and the effects of wall thickness are not expected to be as dramatic.)

3. To determine the location of garter springs, a suitable technique requires development, since it is not possible to locate these using the existing eddy current technique in the absence of girdle wires. Until then, the data obtained from sag measurements can be used to draw conclusions in this respect.

9. REFERENCES

[1] *Periodic Inspection of CANDU Nuclear Power Plant Components*, CAN3-N285.4-M83, (Canadian Standards Association, 1983).

[2] Owen, A. P. (Ontario Hydro), *Private Communication.*

10. ACKNOWLEDGEMENTS

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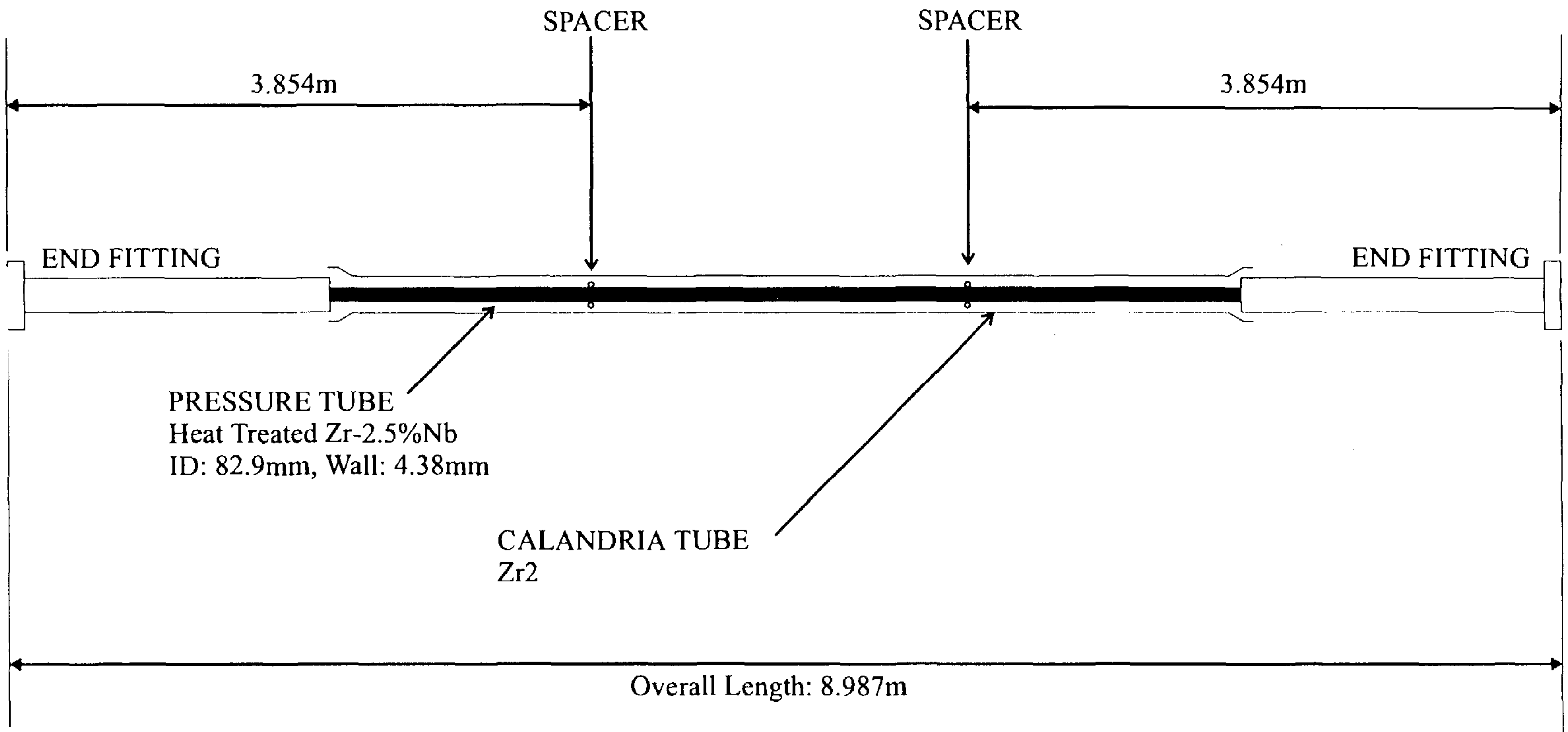


FIGURE 1 Sketch of KANUPP Fuel Channel

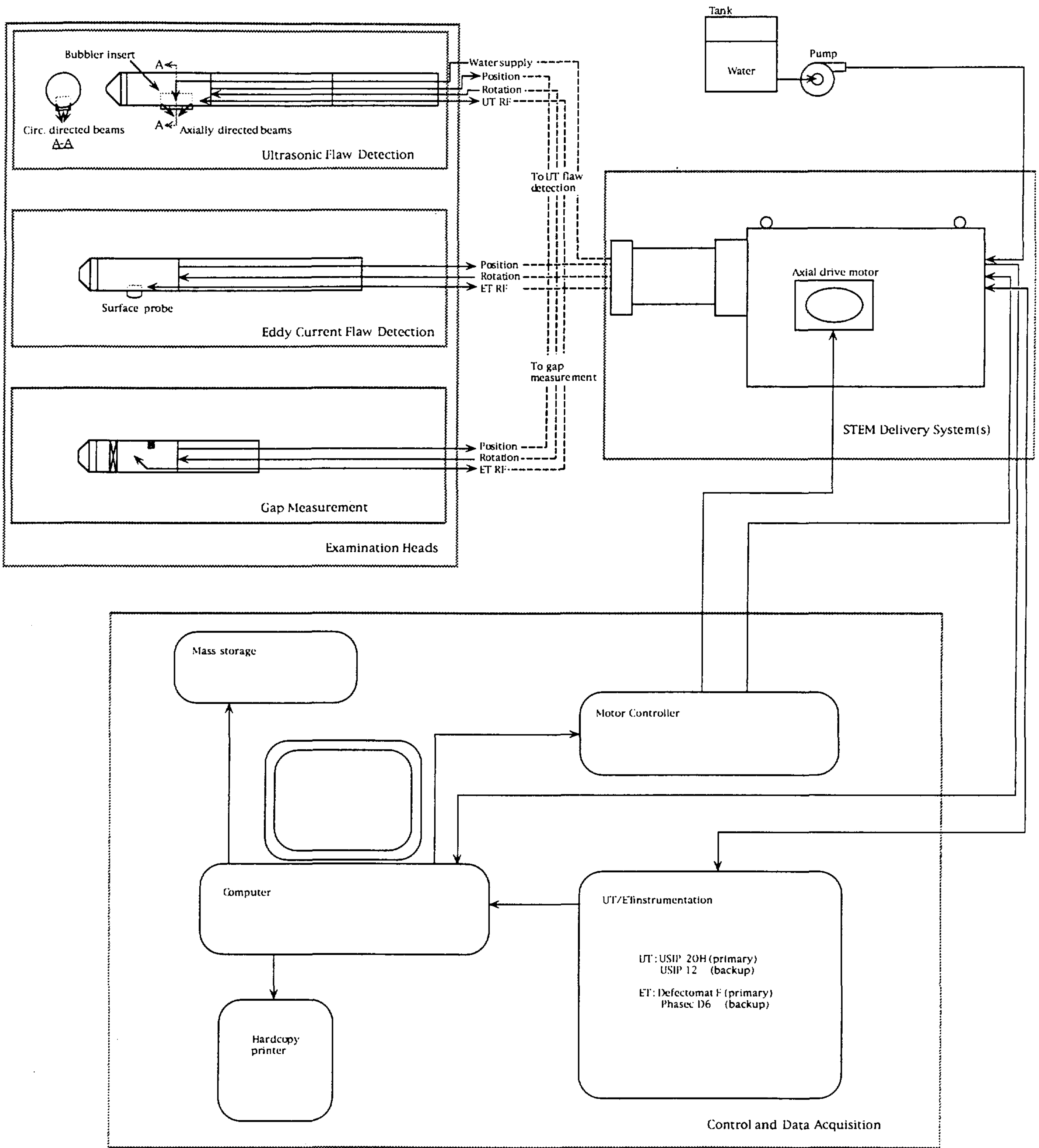


FIGURE 2 : Heads, Delivery System, Control, and Data Acquisition

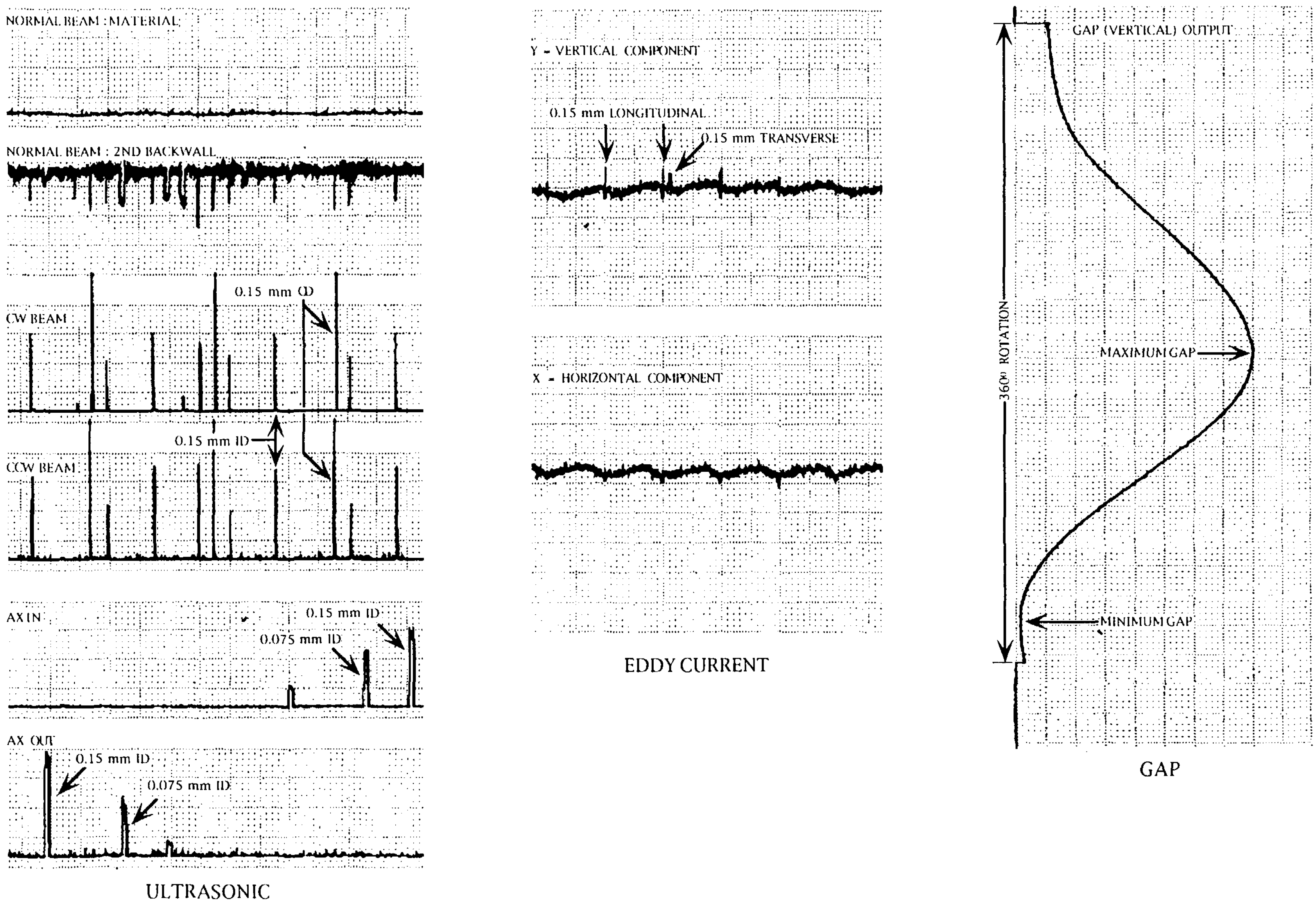


FIGURE 3 : Ultrasonic, Eddy Current, and Gap Calibration Signals

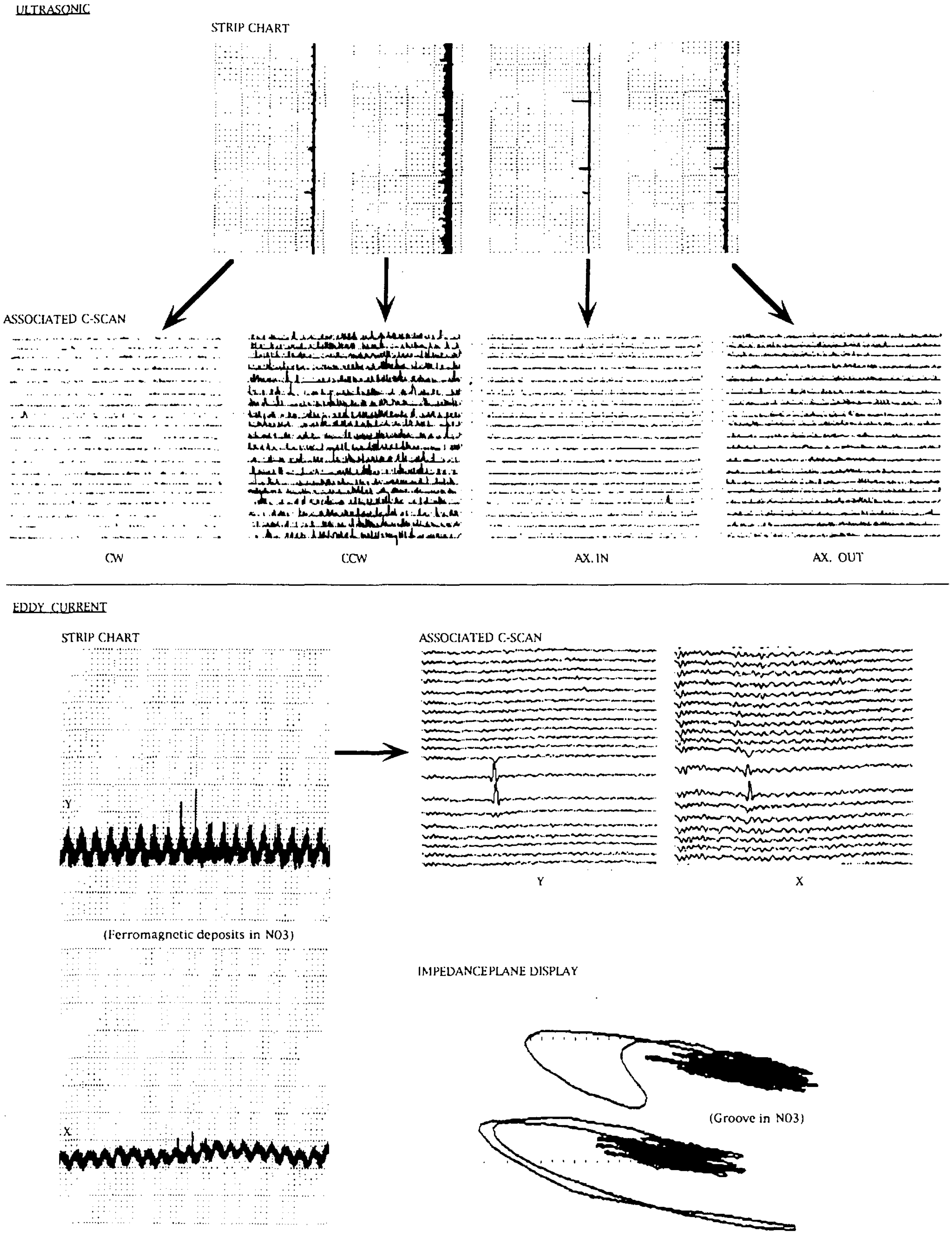
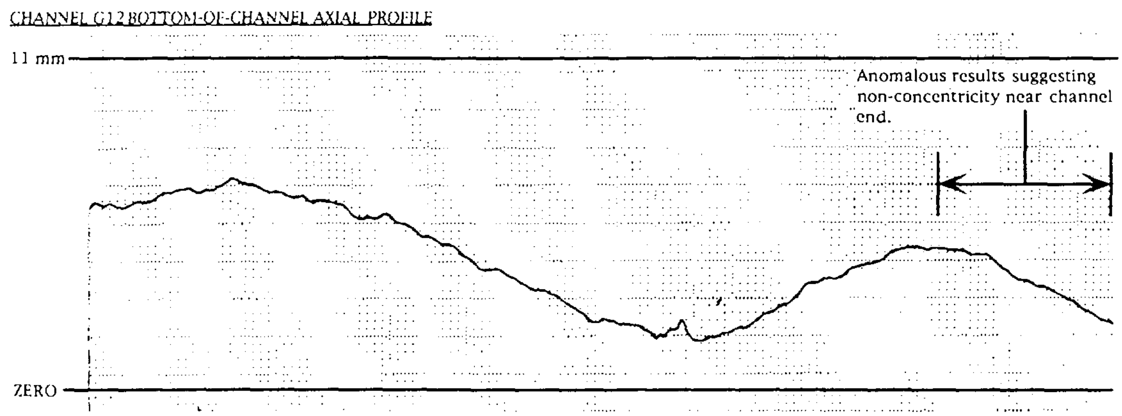


FIGURE 4 : Data Display Formats



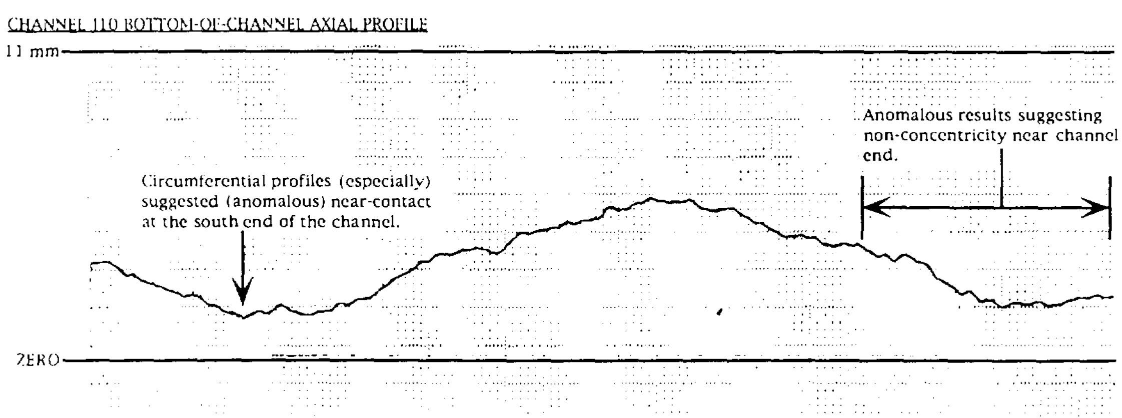


FIGURE 5 : Gap Data Anomaly Examples