International Conference
Nuclear Option in Countries with Small and Medium E
Opatija, Croatia, 1996

HR9800071

ADVANCED NONDESTRUCTIVE EXAMINATION OF THE REACTOR VESSEL HEAD PENETRATION TUBE WELDS

MATO CVITANOVIC, dipl. ing.
VLADIMIR ZADO, dipl. ing.

INETEC
ZAGREB, Koturaska 51

Abstract: Beside a referent code examination requirements, appearance of the service induced flaws on the Reactor Vessel Head (RVH) penetration tube welds forced development of remotely operated examination tools and techniques. Several systems were developed for examination of RVH PWR type while only one system for examination of VVER - 440 type RVH has been developed by Inetec. In this article the most advanced RVH VVER-440 type examination techniques such as ultrasonic, eddy current and visual testing techniques as well as remotely operated tool are described.

1. INTRODUCTION

VVER-440 Pressurized Water Reactor Vessel Heads (RPVH) are equipped with carbon steel penetration tubes (PT) which are fitted into RPVH penetration. The lower parts of the PT are welded to the inner clad surface and base material of the RPVH. Penetration tubes are equipped with corrosion protecting tube made of stainless steel (SS). Another stainless steel tube (heat protecting tube) is inserted into PT and centered into it. The designed distance (gap) between SS corrosion protecting tube and heat protecting tube is three millimeters.

In order to detect any abnormality in the areas of PT and RPVH intersection as well as inside surface of the heat protecting tube the five different end effectors and examination techniques have been developed.

2. SCOPE OF INSPECTION

For the volumetric examination of PT circumferential welds at RPVH intersection, a system which employs contact ultrasonic technique has been developed. Ultrasonic Data Recording and Processing System (UDRPS 2) is used to record, enhance and analyze ultrasonic (UT) data. UDRPS is fully integrated with the Inetec Reactor Vessel Head Inspection Tool to record all ultrasonic and position data as well as to assess indications.

The eddy current technique is applied to examine the surface of the weld and adjacent clad material in order to detect surface abnormalities on the inner part of a RPVH. Another application of the eddy current method is examination of the inner surface of the corrosion protecting stainless steel tubes. The surfaces of a corrosion protecting stainless steel tubes placed into PT are examined by specially designed eddy current probe inserted into a gap. A new end effector is engineered in order to drive inspection probe on an examination required path. A MIZ-18 system is used as frequency generator and data acquisition station for eddy current examinations while data analysis is performed on the HP series 700 computer(s).

Visual testing (VT) of the whole interior of the RPVH and heat protecting tube is performed by using specially designed camera and software which accompanies video signal from the camera and tool positions from the tool controller. The composite signal obtained from the processing board (TARGA+) is recorded on a standard video recorder tapes.
Similarly, visual testing of circumferential PT weld is performed from inside of the RPVH.

3. POSITIONING MANIPULATOR AND INSPECTION PRINCIPLES

3.1. POSITIONING MANIPULATOR DESCRIPTION

The positioning manipulator is based on concept of SM-22, ZETEC's eddy current manipulator. This manipulator consist of arm and pole which are attached to the spacer over the base frame. The pole and arm provides rotation around two vertical axes. The end of the arm is equipped with vertical carriage carrying end effectors. The carriage provides vertical movements (up - down) and rotation around its axis. FIG.1. presents the positioning manipulator and main axes.

3.2. UT SERVICES DESCRIPTION

The Inetec's access to inspection of the PT circumferential weld has been determined in accordance with all mandatory NDE technical requirements and ALARA principles. The examination techniques are defined to provide reliable inspection in the reasonable time interval.

In order to improve and verify designed examination technique and tool the research and experimental works were accomplished on the RPVH mockup situated at Inetec lab.

The main goals of these research works were as follows:

- to detect, locate, characterize and accurately size defects
- to minimize personnel radiation exposure
- to minimize inspection time

The volumetric examination of PT circumferential welds at RPVH intersection is performed by use of simplified ultrasonic equipment designed for reactor vessel inspections which is fully integrated with positioning manipulator and end-effector (EE) controller.

Penetration Tube Weld Ultrasonic Examination

For the PT weld ultrasonic examination a system which employs contact ultrasonic technique has been developed. Due to the acoustic properties of these welds ultrasonic examination is performed by use of longitudinal wave transducers. The primary detecting and sizing transducers to be applied will be 70 degree and creeping wave transducer. The ultrasound beams will be oriented in the three directions - two directions parallel to the weld (clockwise and counterclockwise) and one direction perpendicular to the weld (radially towards the penetration center). A creeping wave, dual element transducer is applied for examination of the material volume close to the weld surface while a dual element, transmit - receive, focused, 70 degree transducer will provide examination coverage of weld root and material between root and surface. The principle of creeping wave probe and examination volume covered by use of these transducers is presented on FIG.2.

With intent to direct ultrasound beam perpendicularly to the crack, transducers are equipped with rotating probe holder. In this way it is enabled that, by using proper skew angle, ultrasound beam attacks particular examination area perpendicularly. The idea of differently positioned defect detection is presented on FIG.3..

UT End Effector

The PT ultrasonic EE is designed in the way that its mounting and disassembling on the positioning manipulator is performed remotely. Thus personnel radiation exposure is reduced to a minimum level.

The UT EE is designed to ensure centering into a PT and scanning motions parallel and perpendicular to the weld as well as follow the shape of the inspection surface. The transducer rotary systems are integrated into a vertical linear motion system together with water supply tubing and transducers wiring. The UT EE examination position is presented on FIG.4.

Ultrasonic Data Recording and Processing System (UDRPS 2) is used to record, enhance and analyze ultrasonic (UT) data. UDRPS is fully integrated with the Inetec Reactor Vessel Head Inspection Tool to record ultrasonic and position data as well as to assess indications.
FIG.5.presents equipment positioning and interconnection schematic.

3.3. EDDY CURRENT TESTING (ECT) SERVICES DESCRIPTION

3.3.1. INSPECTION OF THE STAINLESS STEEL CORROSION PROTECTING TUBE I.D. SURFACE

ECT inspection of the stainless steel corrosion protecting tube inner diameter (I.D.) surface is performed by using rotating eddy current probe in a following manner : probe body is designed in shape of cylinder (FIG.6.), so probe body can be inserted into gap between heat and corrosion protecting tubes. Three ECT 'pancake' coils are mounted on a probe body. Inside tube's gap probe body rotates around tubes axis. Corrosion protecting tube I.D. surface can be examined 290 mm from bottom of the inner tube. After probe is inserted into gap, it is rotated and pulled out. Inspection is provided using 3-coil rotating probe i.e. 3 'pancake' coils are mounted on probe body, separated 120° in circumference. Coils are designed as low-frequency probe. This gap-scanner rotation probe provides required sensitivity and resolution so it is possible to detect, locate and measure both circumferential and axial cracks.

Applied probe has efficient frequency range 30-200 kHz. A standard depth of penetration while operating at frequency of 30 kHz is 2.5 mm. If operating frequency is 200 kHz, depth of penetration is approx. 1 mm, so surface breaking defects are easily detected.
Four surface breaking notches are presented on FIG.7. All displayed notches are 0.5 mm deep and 1.27 mm wide. The length of notches varies between 3 - 10 mm as it is visible from C-scan display.

Experience with steam generators tube inspections has showed that eddy current method quickly provides reliable information about existence of even the smallest defects. For surface defects detection an eddy current inspection is preferable in comparison to other nondestructive examination techniques.

INSPECTION LIMITATIONS :

Possible limitations during inspection may be deposits inside tube gap and ovality of tubes resulting in locally decreased gap width. The final result is resistance to probe motion in both axial and circumferential direction. If gap is restricted to probe motion due to deposit existence, tube is cleaned by use of specially designed cleaner while in the case of tube ovality "blade" probe will be used.

INSPECTION SCHEME :

Using positioning manipulator, probe is positioned to area of interest. Eddy current data are generated using "MIZ-18" Remote Data Acquisition Unit and recorded on an optical data disks where also data evaluation results will be permanently stored.
Data evaluation is provided using appropriate analysis software for rotating probe data, i.e. C-scan while analysis result data base is generated in Data Management System.
The simplified scheme of inspection organization and data flow is given on FIG.8..

3.3.2. INSPECTION OF THE PENETRATION WELD SURFACE

The penetration weld surface inspection is performed using eddy current probe designed for weld testing. Probe operates in differential mode and it is designed to minimize undesired features affecting this scan area, as probe lift-off, permeability variations and conductivity changes. Probe frequency range of interest is 30-200 kHz. Standard depth of penetration while operating at frequency of 30 kHz is approx. 2.5 mm. Weld is scanned on it's whole circumference starting on a minimum radius, than radius is incremented and scanning is repeated until whole weld surface is tested. FIG.9. represents end effector position while testing weld surface.

The two surface breaking notches detected by weld scan probe are shown on FIG.10. The notches are 1 and 0.5 mm deep.

INSPECTION SCHEME :

Inspection scheme and data flow are the same as during inspection of the stainless steel corrosion protecting tube ID surface, chapter 3.3.1. with differences in specific routine of data collection and data evaluation.

3.4. VISUAL INSPECTION

VT SERVICE DESCRIPTION

Visual testing of RPVH will be performed on three areas of interest:

- interior of RPVH
- interior of inner stainless steel heat protection tubes
- PT circumferential welds

Remote visual testing technique will be applied as is presented on FIG.11.- Sample VT inspection drawing.

HEAT PROTECTION TUBES VISUAL TESTING

The inner surface of heat protection tubes will be visually tested by camera equipped with radial viewing head and integral light.

The RPVH positioning manipulator with attached visual testing end effector will be positioned under the penetration to be inspected. The camera, mounted on vertical carriage, will be driven into penetration up to the top of flange. The scan will be performed by camera rotation from 0 to 360 degrees. When the scan is finished, vertical carriage will be incremented down for next scan and camera will be rotated back to initial position. After that, camera will be incremented again.

Described steps will be repeated until the whole surface of heat protection tube will be visually tested. The increment value will be set to provide 10% overlap.

PT CIRCUMFERENTIAL WELDS AND RPVH VISUAL TESTING

The surface of PT circumferential welds will be visually tested by camera equipped with prismatic viewing head and integral light.

The RPVH positioning manipulator with attached visual testing end effector will be positioned under the penetration to be inspected. The camera will be driven by vertical carriage near the PT circumferential weld. The scan will be performed by means of prism rotation in camera viewing head. The increment will be performed by means of camera rotation around PT axis (camera will rotate around center line of penetration in horizontal plane).

Described steps will be repeated until the whole surface of PT circumferential weld will be visually tested. The angle of increment will be set to provide 10% overlap.

VISUAL TESTING EQUIPMENT

Visual testing equipment consists of:

- REES R93 Mk3 B/W camera
- REES radial viewing head with light
- REES prismatic viewing head with light
- REES camera control unit
- PC with TARGA+ video processor board
- VHS video cassette recorder
- B/W video monitor
- visual standard 1/32" black lines on 18% natural gray card

B/W camera is used because it has better life time in the high irradiated areas and it has better resolution. To make sure that video system with camera and light provide required resolution visual standard is used.
The camera control unit provides remote control of following camera functions: focus, iris, light intensity and prism rotation.

In order to record position data and video signal accompanied, the video composite signal from camera control unit is overlapped with real time coordinates by PC with TARGA+ board. The real time coordinates are being obtained from the tool control system. Overlapped picture is recorded on the video cassette recorder in PAL video standard.

Before inspecting of RPVH penetration the header picture containing all significant data will be used for announcing. The operators voice could be recorded on the tape as well as video signal.

4. EQUIPMENT SETUP

The equipment is preferably set up prior the RPVH is positioned on its stand. Assembling of the manipulator is provided through a manway placed in the floor for the case that RPVH is positioned on its stand. The manipulator is connected to remote acquisition system. Electrical and mechanical functions are tested afterwards. Therefore there is need to enter the RPVH only during the disassembling of the manipulator.

Following actions with tooling such as changing the end effector or other maintenance activities during the inspection take place from outside.

5. INSPECTION SEQUENCE

Reactor vessel head inspection consists of visual testing, eddy current testing and ultrasonic testing. The inspection sequence is as follows:

1) The camera for inside tube VT is mounted to manipulator carriage. The manipulator is aligned with the penetration to be inspected. The camera is driven up and entered the tube. When camera is reached the PT flange the scanning sequence is started. The camera is rotated around its axis for a one whole turn 360° scans the completely tube.

2) The camera for VT of welding surface is mounted to vertical carriage. The manipulator is aligned with the penetration to be inspected. Scanning is performed with rotating the camera around the vertical axis.

3) The MRPC probe is mounted to manipulator carriage. The manipulator is aligned with the penetration to be inspected. The probe is driven up to the maximum inspection height (about 300 mm above the tube end). After probe is placed at required position, it starts to rotate and moves down at the same time. During performance of this scanning motions EC data recording is performed.

4) The weld surface EC inspection probe with its drive system is mounted to manipulator carriage. The manipulator is aligned with a penetration to be inspected and the probe is driven up to the surface to be tested. The EC data are collected during rotation of the probe around PT. After complete cycle, a small horizontal movement of the probe drive system is performed.
The sequence started again until inspection plan for this penetration is completed.

5) After positioning manipulator is reached desired penetration tube position, the centering device of UT EE is inserted into a penetration tube. Entrance of the centering device into a PT is monitored via video system applied. After centering in the tube, transducers are placed into a contact with an examination surface. The information about contact between transducers and examination surface is controlled by non-contact sensors. The couplant recovery system controlled by sensors starts to operate and supplies transducers with water. At this moment the preprogrammed scanning sequence is started. When scanning sequence is finished all activities are stopped automatically. An operator is lifted down the UT EE and examination sequence may be started again to finish the inspection plan.

FIGURE 1.

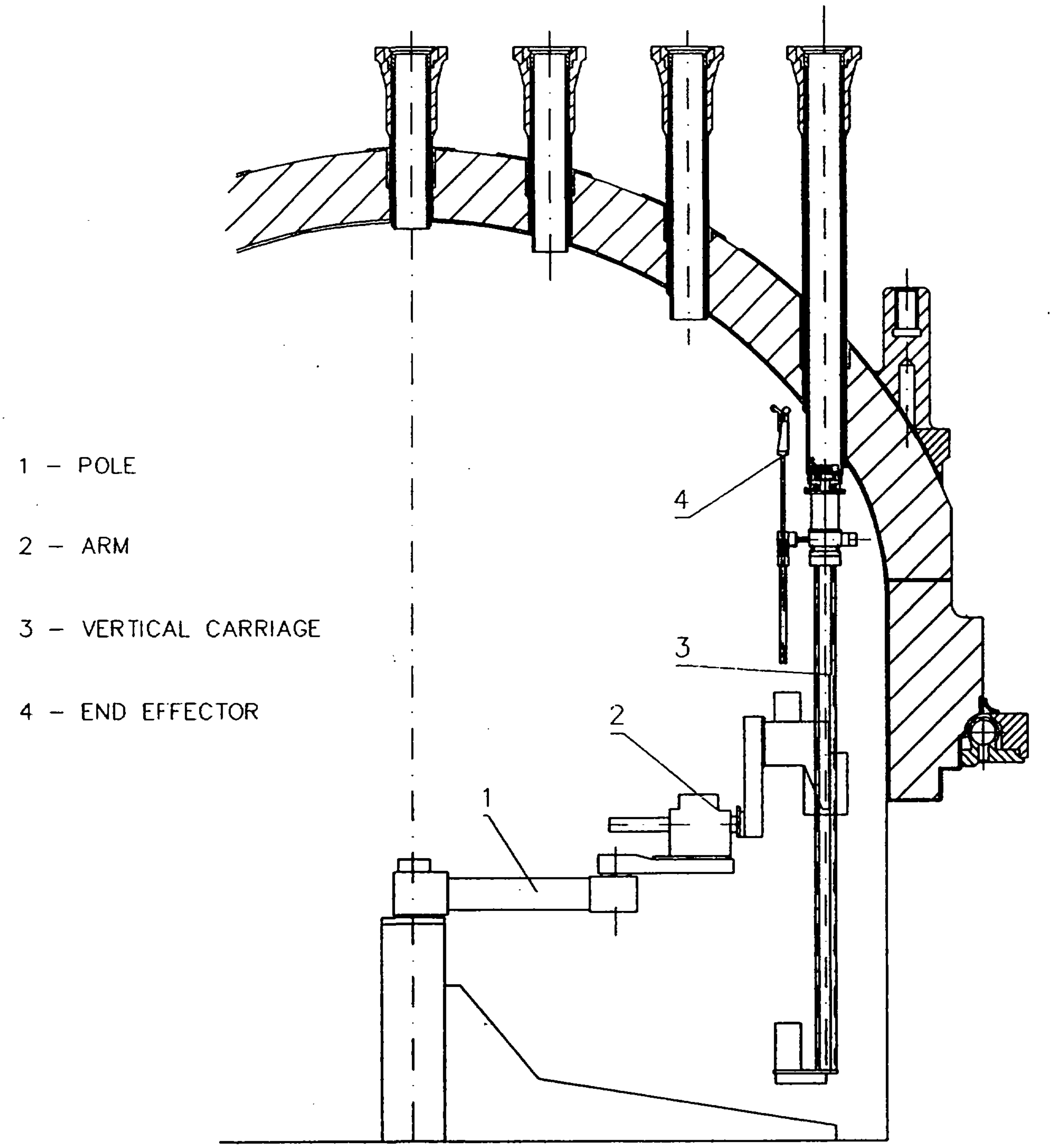
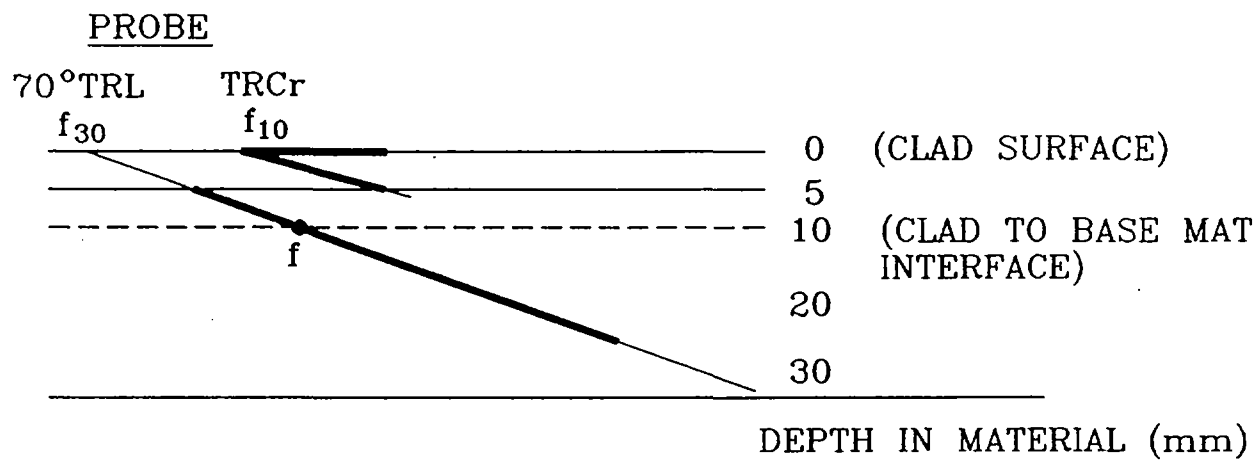


FIGURE 2.


PROBE
70°TRL
f_{30}
TRCr
f_{10}
0 (CLAD SURFACE)
5
10 (CLAD TO BASE MAT. INTERFACE)
f
20
30
DEPTH IN MATERIAL (mm)

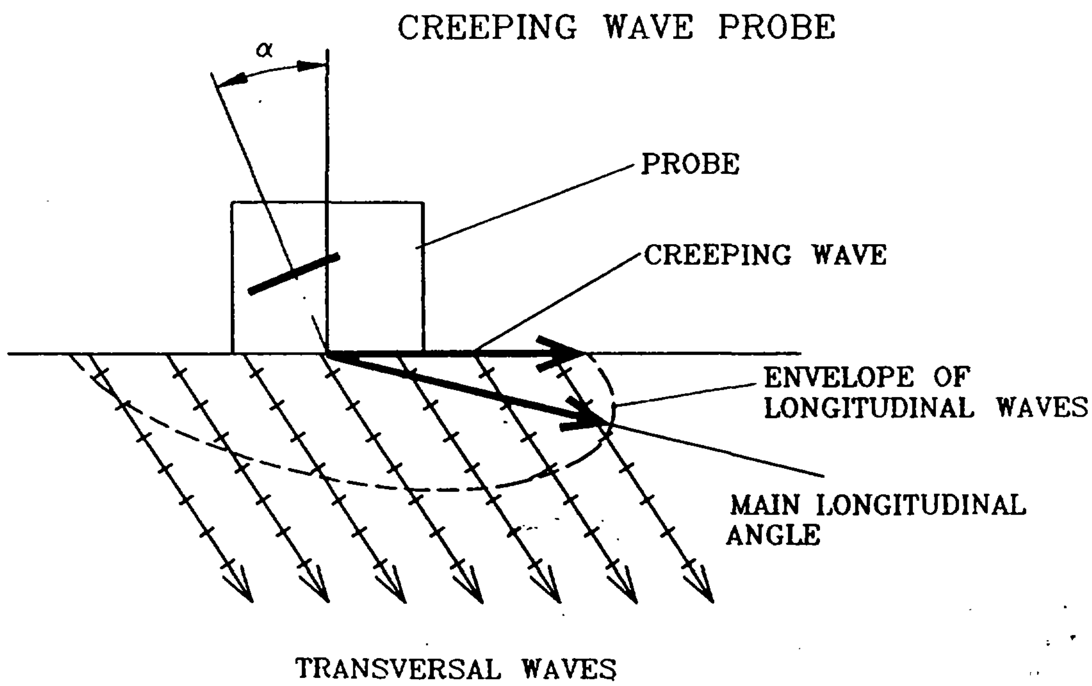
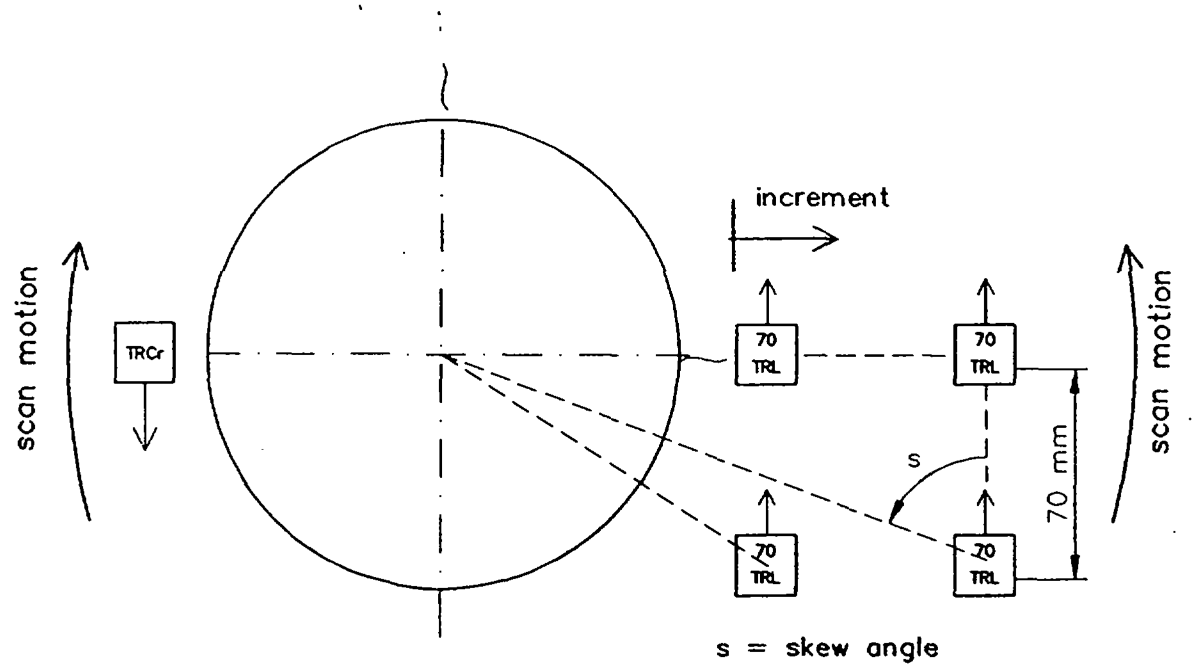

CREEPING WAVE PROBE
α
PROBE
CREEPING WAVE
ENVELOPE OF LONGITUDINAL WAVES
MAIN LONGITUDINAL ANGLE
TRANSVERSAL WAVES

FIGURE 3. CIRCUMFERENTIAL SCANNING
(RADIAL DEFECTS DETECTION)



RADIAL SCANNING
(CIRCUMFERENTIAL DEFECTS DETECTION)

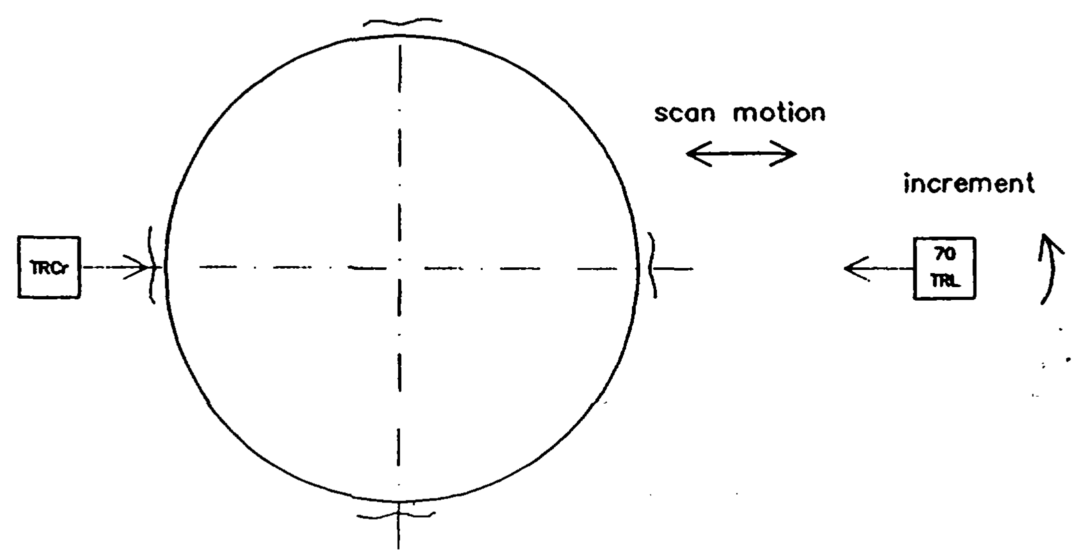
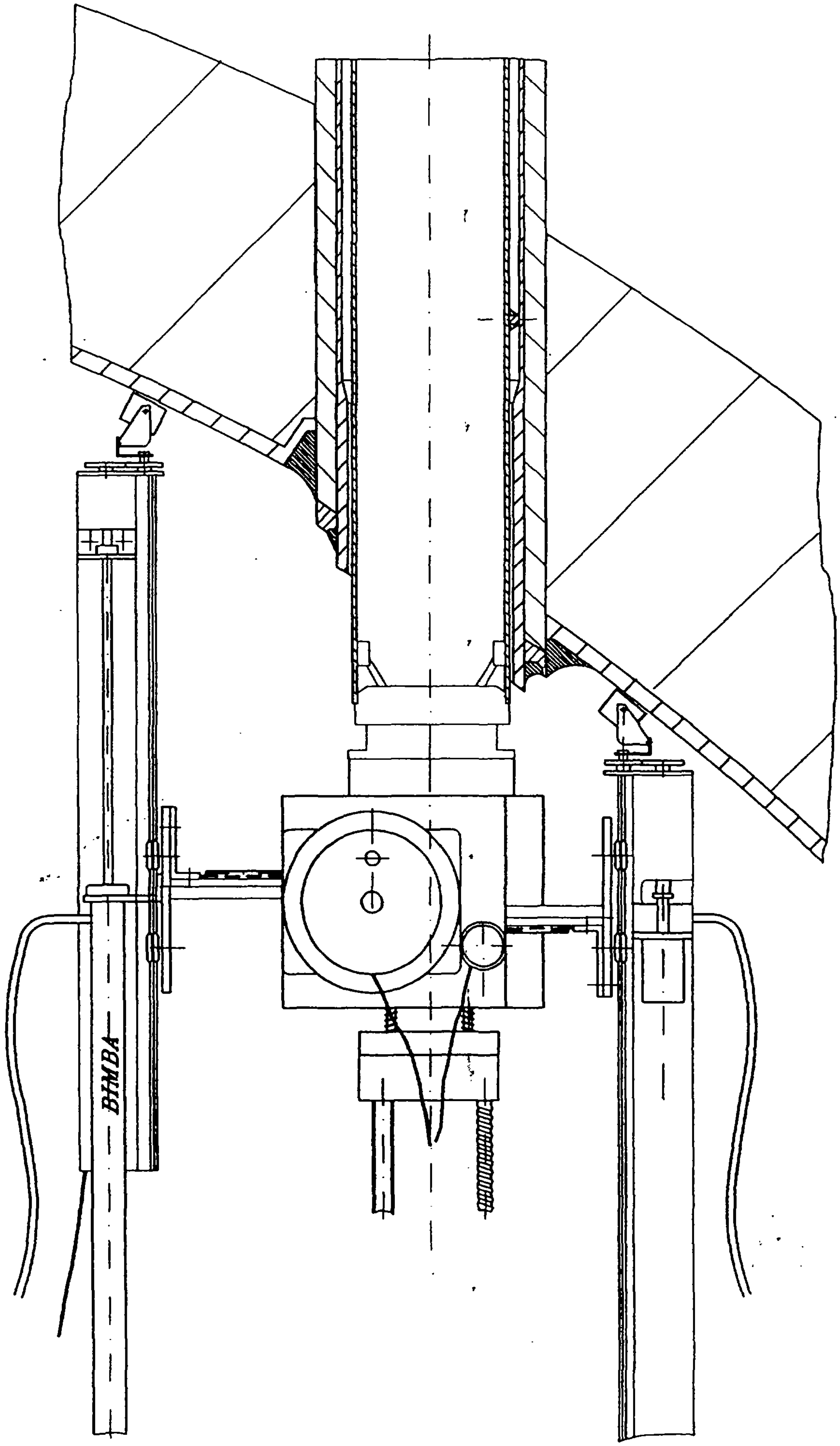


FIGURE 4.



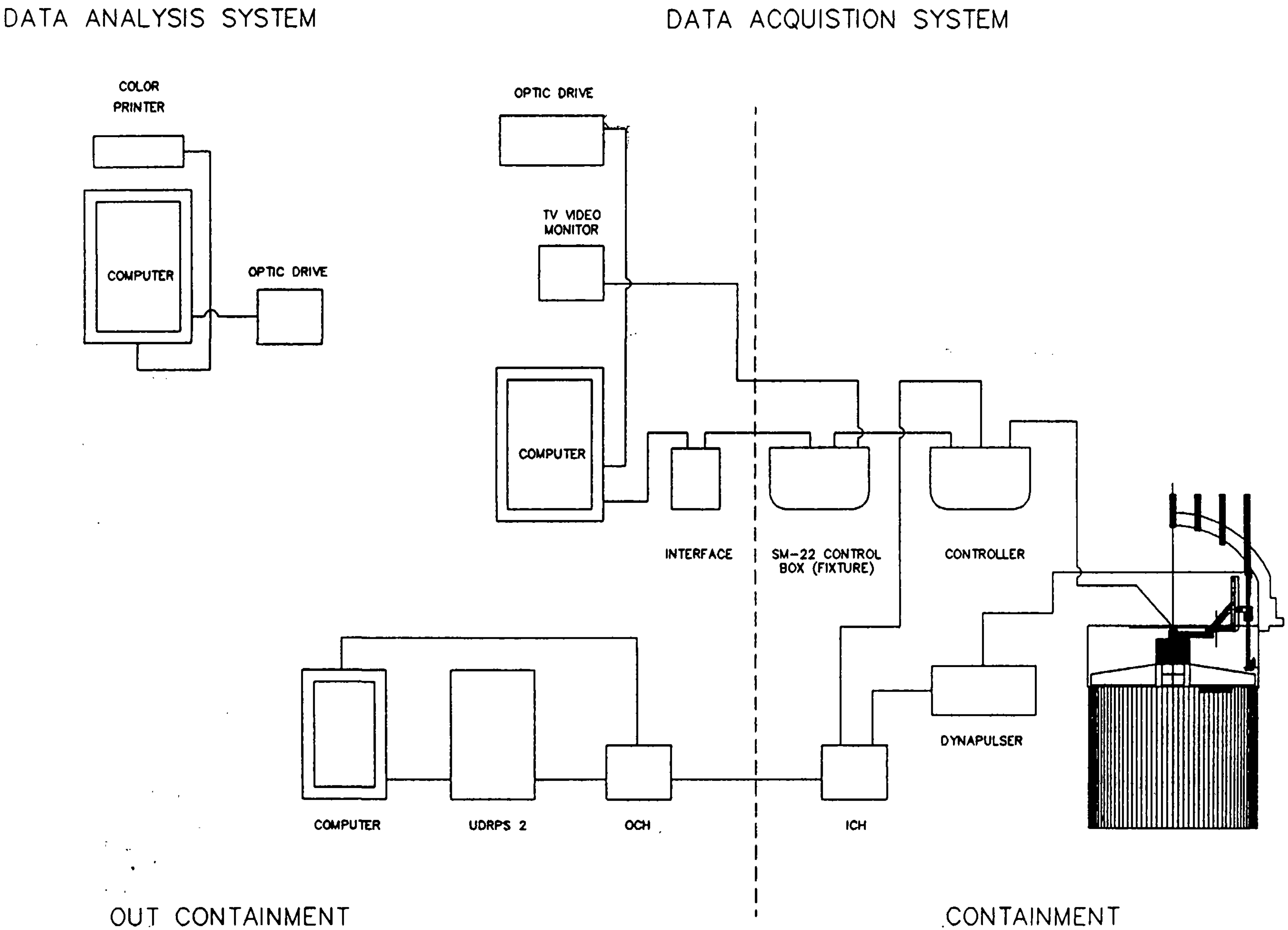


FIGURE 5

FIGURE 5.

FIGURE 6.

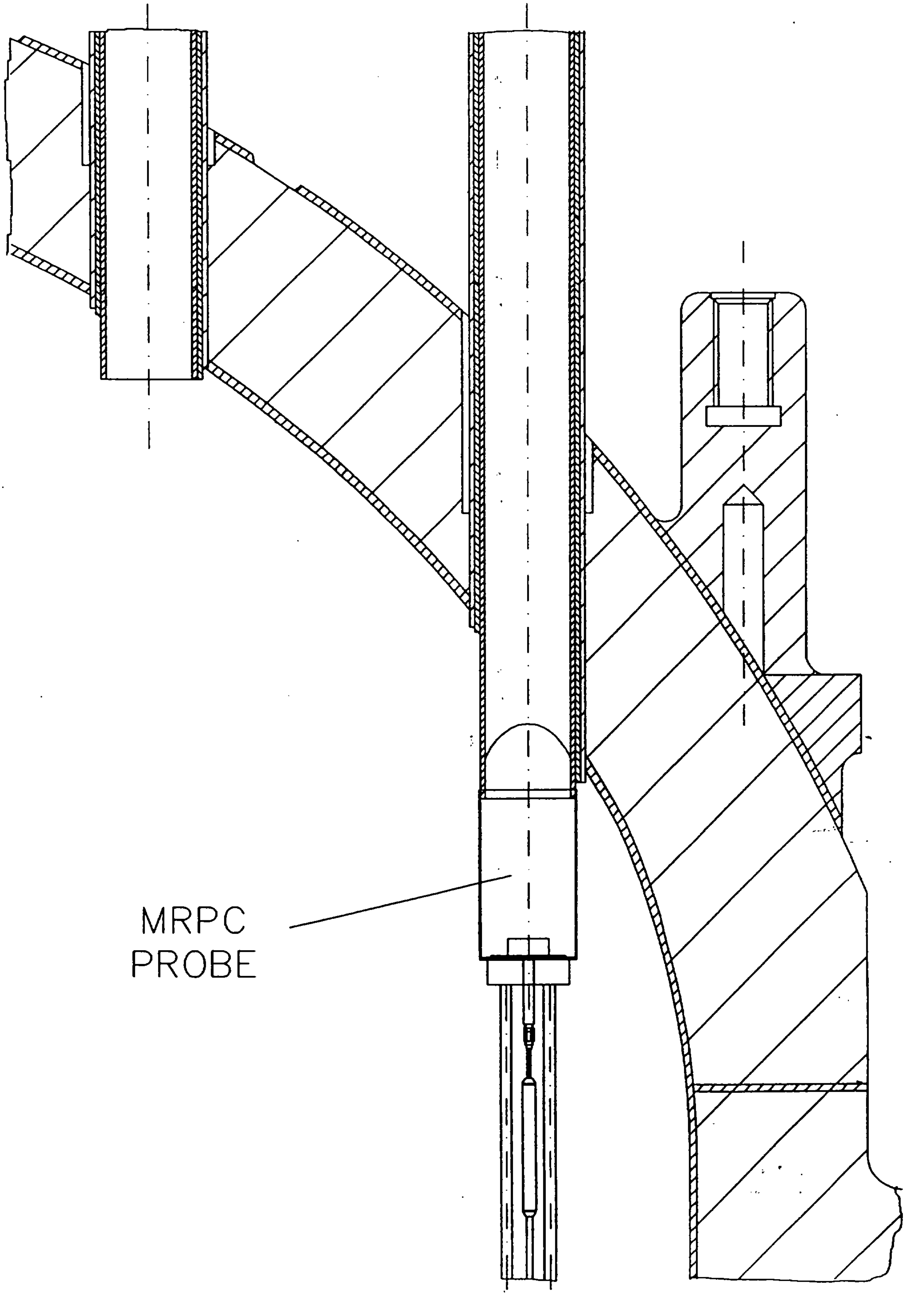
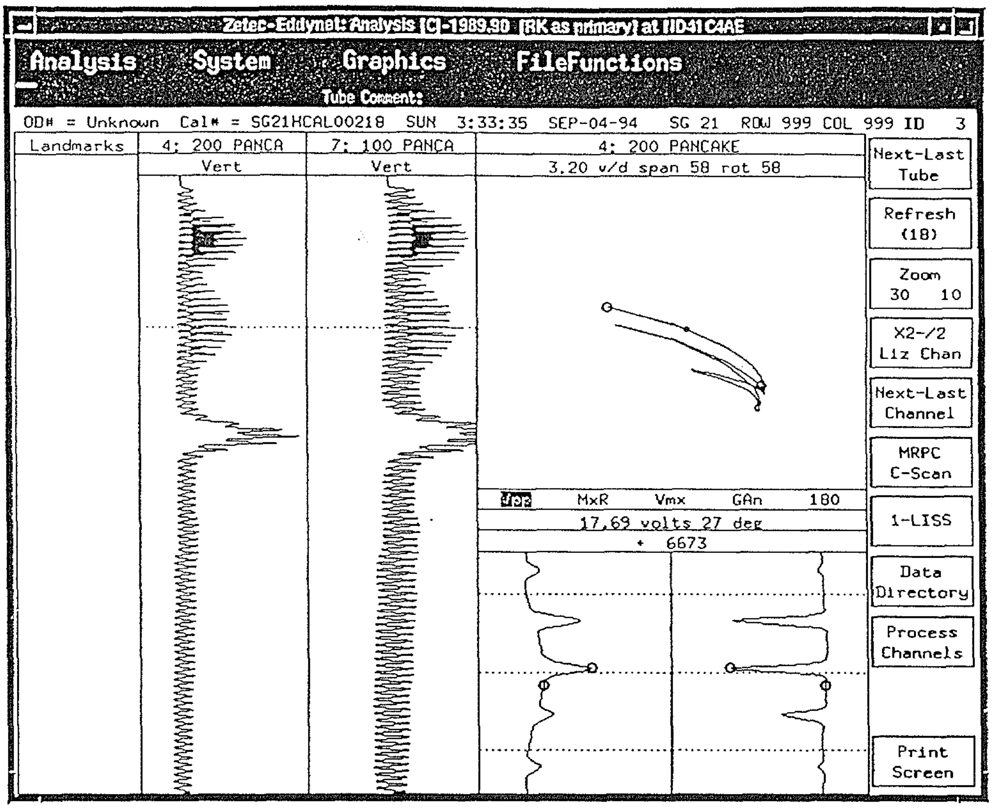
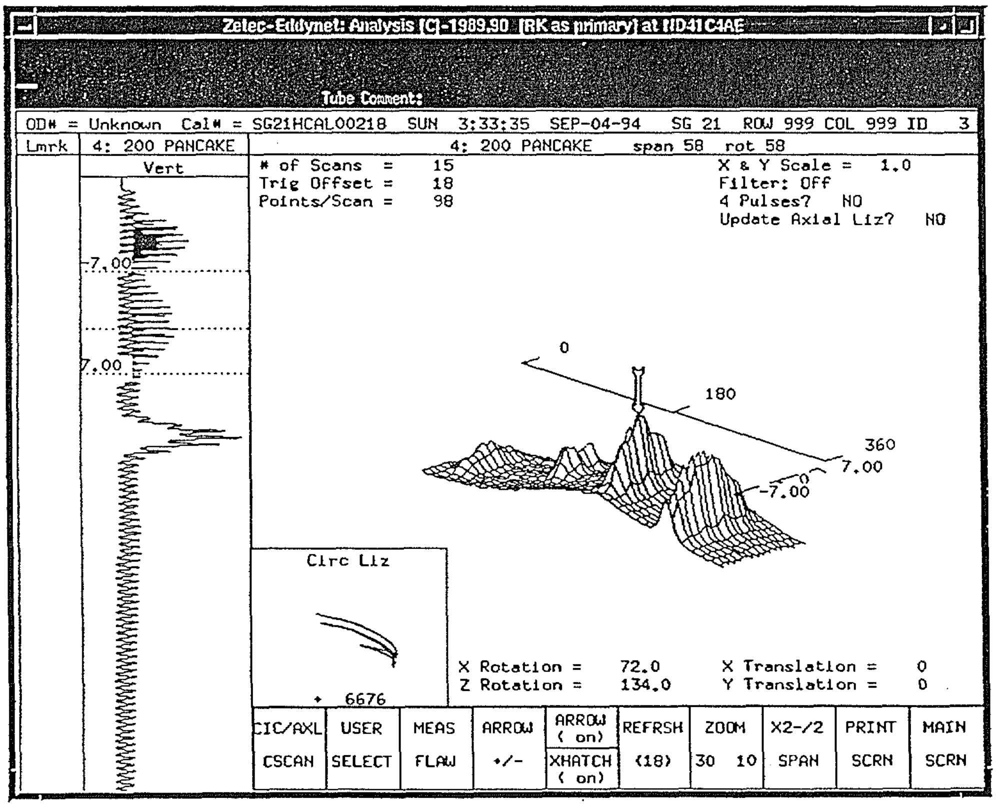


FIGURE 7.


Zetec-Eddynet: Analysis [C]-1989,90 [RK as primary] at IID41C4AE
Analysis
System
Graphics
FileFunctions
Tube Comment:
OD# = Unknown Cal# = SG21HCAL00218 SUN 3:33:35 SEP-04-94 SG 21 ROW 999 COL 999 ID 3
Landmarks
4: 200 PANCA
7: 100 PANCA
4: 200 PANCAKE
Vert
Vert
3.20 v/d span 58 rot 58
MxR Vmx GAn 180
17.69 volts 27 deg
6673
Next-Last Tube
Refresh (18)
Zoom 30 10
X2-/2 Liz Chan
Next-Last Channel
MRPC C-Scan
1-LISS
Data Directory
Process Channels
Print Screen


Zetec-Eddynet: Analysis [C]-1989,90 [RK as primary] at IID41C4AE
Tube Comment:
OD# = Unknown Cal# = SG21HCAL00218 SUN 3:33:35 SEP-04-94 SG 21 ROW 999 COL 999 ID 3
Lmrk
4: 200 PANCAKE
4: 200 PANCAKE span 58 rot 58
Vert
# of Scans = 15
Trig Offset = 18
Points/Scan = 98
X & Y Scale = 1.0
Filter: Off
4 Pulses? NO
Update Axial Liz? NO
-7.00
7.00
0
180
360
7.00
-7.00
Circ Liz
6676
X Rotation = 72.0
Z Rotation = 134.0
X Translation = 0
Y Translation = 0
CIC/AXL CSCAN
USER SELECT
MEAS FLAW
ARROW +/-
ARROW (on) XHATCH (on)
REFRSH (18)
ZOOM 30 10
X2-/2 SPAN
PRINT SCRN
MAIN SCRN

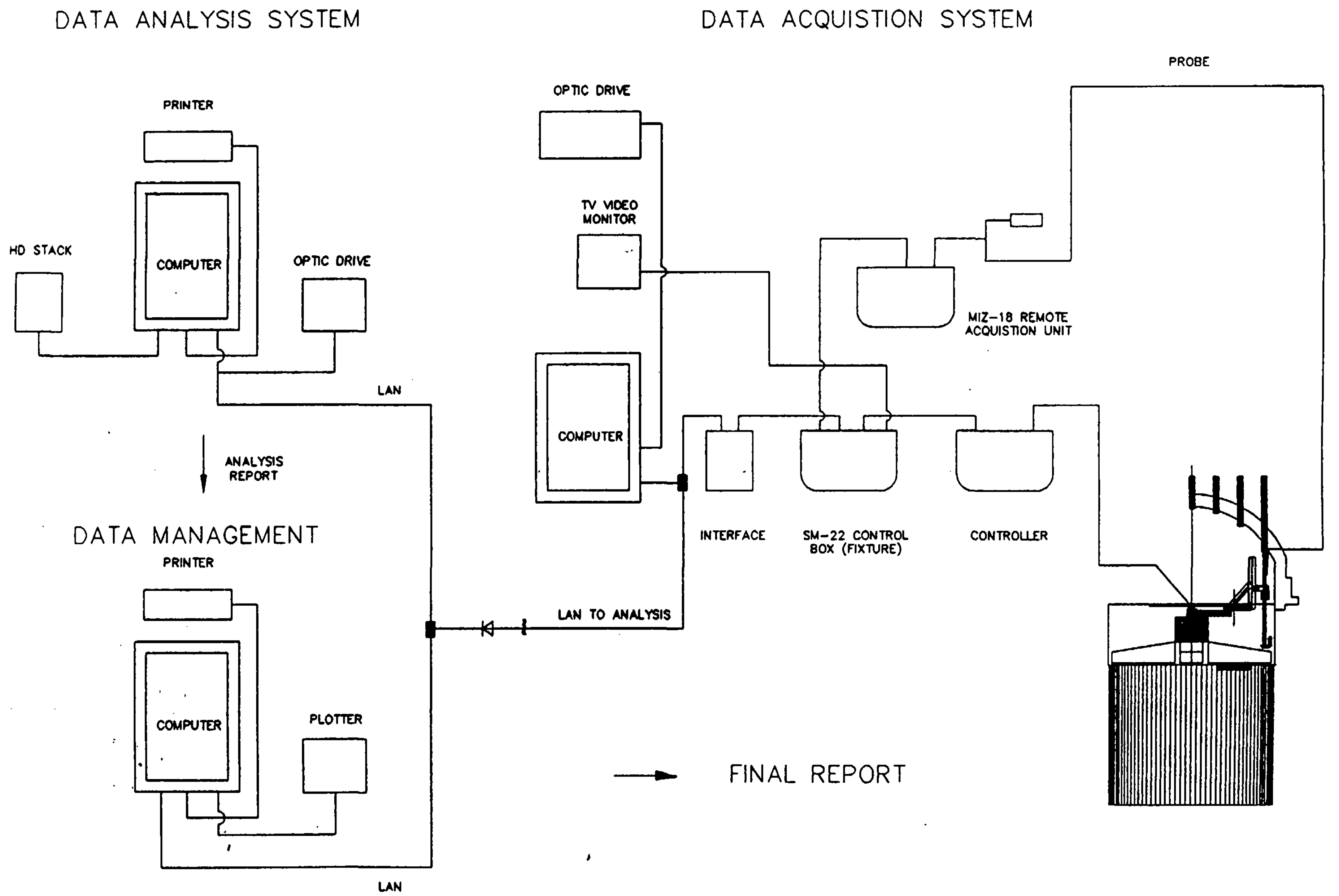

DATA ANALYSIS SYSTEM
DATA ACQUISTION SYSTEM
PRINTER
HD STACK
COMPUTER
OPTIC DRIVE
LAN
ANALYSIS REPORT
DATA MANAGEMENT
PRINTER
COMPUTER
PLOTTER
LAN
OPTIC DRIVE
TV VIDEO MONITOR
COMPUTER
PROBE
MIZ-18 REMOTE ACQUISTION UNIT
INTERFACE
SM-22 CONTROL BOX (FIXTURE)
CONTROLLER
LAN TO ANALYSIS
FINAL REPORT

FIGURE 8.

FIGURE 9.

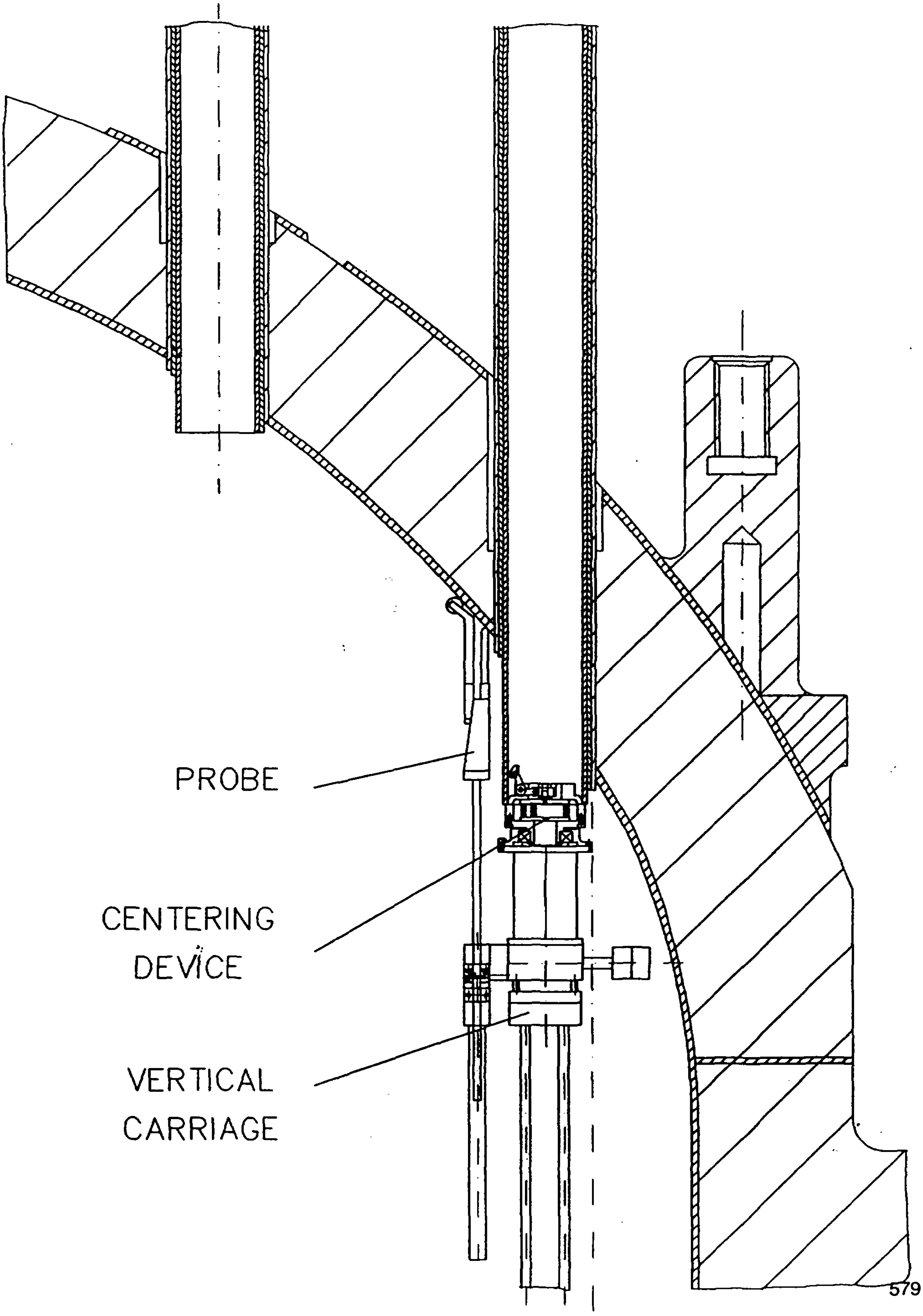
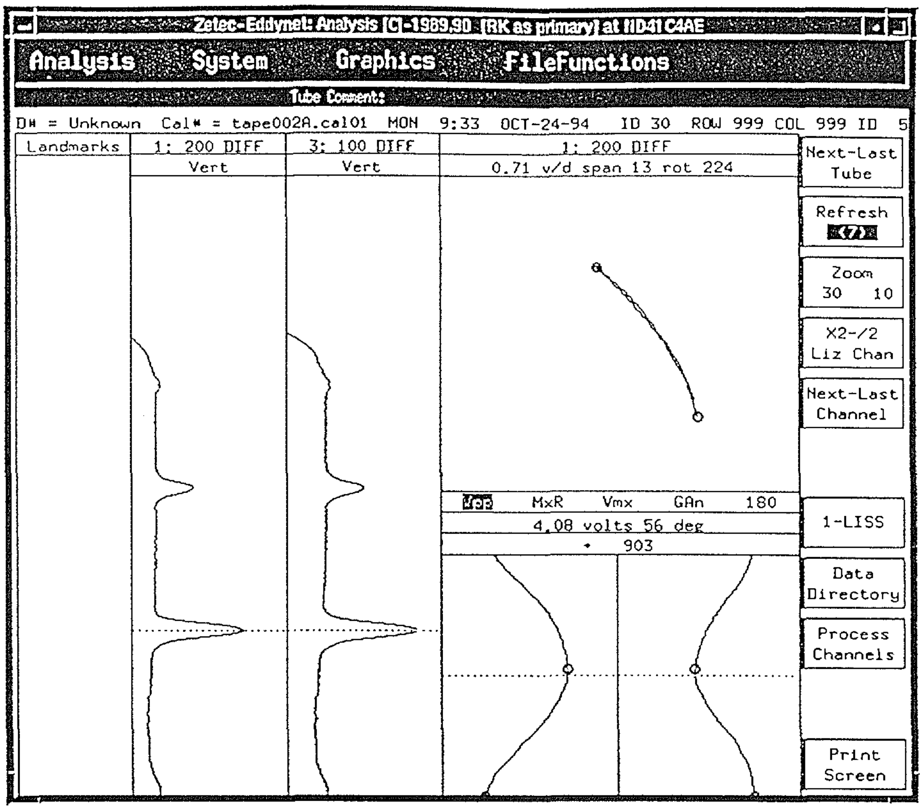


FIGURE 10.


Zetec-Eddynet: Analysis (C)-1989,90 [RK as primary] at IID41 C4AE
Analysis
System
Graphics
FileFunctions
Tube Comment:
D# = Unknown Cal# = tape002A.cal01 MON 9:33 OCT-24-94 ID 30 ROW 999 COL 999 ID 5
Landmarks
1: 200 DIFF
Vert
3: 100 DIFF
Vert
1: 200 DIFF
0.71 v/d span 13 rot 224
Next-Last Tube
Refresh
Zoom 30 10
X2-/2 Liz Chan
Next-Last Channel
MxR Vmx GAn 180
4.08 volts 56 deg
903
1-LISS
Data Directory
Process Channels
Print Screen

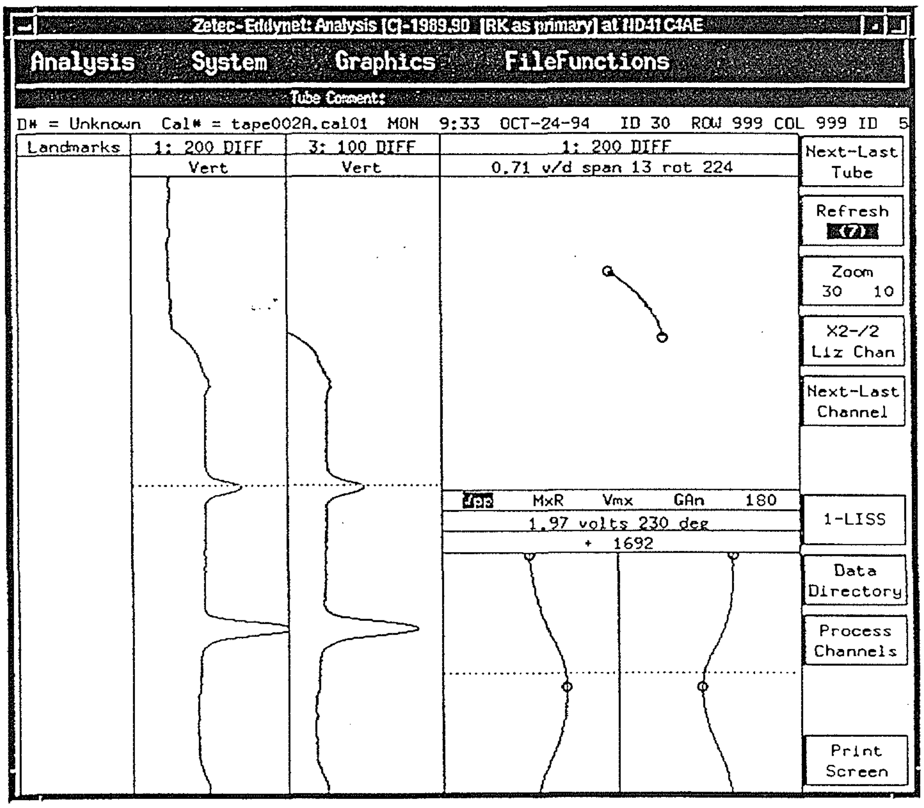
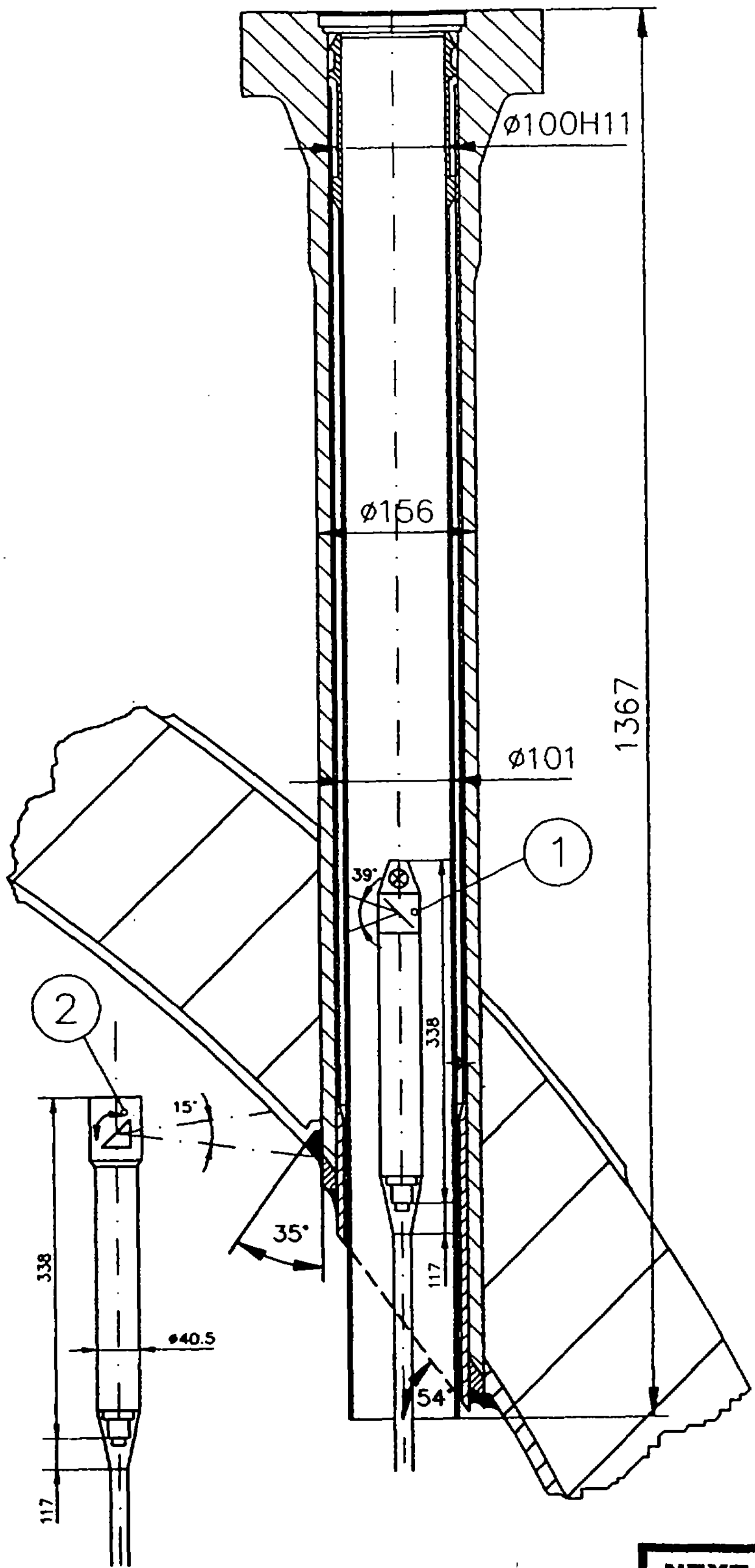

Zetec-Eddynet: Analysis (C)-1989,90 [RK as primary] at IID41 C4AE
Analysis
System
Graphics
FileFunctions
Tube Comment:
D# = Unknown Cal# = tape002A.cal01 MON 9:33 OCT-24-94 ID 30 ROW 999 COL 999 ID 5
Landmarks
1: 200 DIFF
Vert
3: 100 DIFF
Vert
1: 200 DIFF
0.71 v/d span 13 rot 224
Next-Last Tube
Refresh
Zoom 30 10
X2-/2 Liz Chan
Next-Last Channel
MxR Vmx GAn 180
1.97 volts 230 deg
1692
1-LISS
Data Directory
Process Channels
Print Screen

FIGURE 11.



NEXT PAGE(S) left BLANK

REES R93 Mk3 CAMERA WITH:

① – REES RADIAL VIEWING HEAD
② – REES PRISMATIC VIEWING HEAD