DATA INTERPRETATION AND DEFECT ASSESSMENT IN PIPELINE PIGGING

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A thesis submitted in partial fulfillment of the requirements for the Degree of
Master of Technology
(Pipeline Engineering)

By

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Approved

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CERTIFICATE

This is to certify that the work contained in this thesis titled **"DATA INTERPRETATION AND DEFECT ASSESSMENT IN PIPELINE PIGGING"** has been carried out by Praphul.KP. under my supervision and has not been submitted elsewhere for a degree.

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Date

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ABSTRACT

In pipelines transporting hazardous substances like hydrocarbons, safety is of predominant importance. Any malfunction will cause unnecessary stoppage in product supply and environmental pollution affecting public in large. Only solution is a periodical health monitoring system for pipeline. Intelligent pigging is one proven method. Result of an intelligent pig inspection is an inspection report with a list of defects which should be assessed by an expert analyst. Entire process of in line inspection, will give best result only when combining with a trustworthy defect assessment methodology. This paper presents a method for defect assessment in pipelines with reference to practical cases of Caliper/MFL inspections conducted in different pipelines and international codes and standards.

CONTENTS

SYMBOLS AND ABBREVIATIONS

A = Geometric parameter related to the wall thickness

Ai,pit = Area of the 'i'th idealised 'pit' in a complex shaped defect (mm2).

Apatch = Area of an idealised 'patch' in a complex shaped defect (mm2).

c = Circumferential length of corroded region (mm).

di = Depth of an individual defect forming part of a colony of interacting defects (mm). Average depth of 'i'th idealised 'pit' in a progressive depth analysis of a complex shaped defect (mm).

dj = The 'j'th depth increment in a progressive depth analysis of a complex shaped defect (mm).

ERF = Estimated Repair Factor = MOP/Psafe ,Where Psafe is the safe operating pressure as calculated by anomaly assessment method.

l = Longitudinal length of corroded region (mm).

MAOP =Maximum Allowable Operating Pressure

MFL = Magnetic Flux Leakage

nwt = Nominal wall thickness

Pcorr = Allowable corroded pipe pressure of a single longitudinal corrosion defect under internal pressure loading (N/mm2).

POD = Probability of detection

Q = Length correction factor.

RP = Recommended Practice

SMTS=Specified minimum tensile strength (N/mm^2)

StD(X) = Standard deviation of random variable X.

S= Longitudinal spacing between adjacent defects (mm).

UT = Ultrasonic technique

ULS = Ultimate Limit State

W= Anomaly/feature dimension (Width) in the circumferential direction and opening dimension for cracks (if applicable).

WT = Wall Thickness

$(X)^*$ = Characteristic value of X.

εd = Factor for defining a fractile value for the corrosion depth.

φ = Circumferential angular spacing between adjacent defects (degrees).

γd = Partial safety factor for corrosion depth.

γm = Partial safety factor for longitudinal corrosion model prediction.

1. INTRODUCTION

Pipelines are considered as the most efficient way of transferring fluids (oil and gas) over long distances. Despite this high-efficiency, there have been reasons for concern, principally because a large part of the existing pipeline networks are coming to the end of their useful life. Consequently it is necessary to be able to monitor, evaluate and to guarantee their structure as a whole, taking precautions against leaks and consequently protecting the environment and the population.

In order to ensure the integrity of the system, the pipelines are periodically inspected for damage caused by corrosion and other factors using a device called a'pig'. The pig which is launched at one end of a line section and retrieved at the other end is propelled down the line by the action of differential pressure of fluid. The pig, in brief, is a magnetizer–sensor assembly, which employs different technique for assessing the condition of pipe. Use of intelligent pigs has been increasing rapidly because of their proven benefits, booming potentialities and legal requirements.

The result of an intelligent pig inspection is a report with a list of defects. Evaluation of pipelines typically generates about 10 GB of data for every 100 km of pipeline inspected. To gain the full benefit from an inspection the pipeline operator must understand the inspection process, and what the list of defects means for the immediate and the future integrity of the pipeline.

But in-line inspections provide data that are not direct measures of the severity or dimensions of defects. So, data must be interpreted by trained analysts. Regardless of the methods used, there will be errors in the results such as wrong classification or categorization of defects. These errors are to be avoided carefully or else it may take away entire benefit of the inspection. Pigging is always an expensive exercise, involving huge involvement of financial and human investments. Faulty interpretation will certainly affect the good will of the pigging company along with huge financial losses. However the best the technology be, the importance of human operator cannot be neglected at any cost in this era. In this project some important aspects of pipeline pigging data interpretation has been dealt along with certain related requirements.

2. LITERATURE REVIEW

While assessing intelligent pig result, better understanding of the multistaged process of Geometry /MFL/ Ultrasonic pigging processes and type of defects that can be identified by each method are necessary. Paper titled 'Understanding the results of an intelligent pig inspection', published in 'Penspen integrity', an organization for pipeline integrity management describes briefly what to look for in a pig report.

Another excellent work from Penspen, by Prof. Phil Hopkins and Roland Palmer Jones titled 'Getting more from your intelligent pig report' gives detailed guidance on understanding the report in assessing large, complex corrosion defects with a brief outlook on how the data looks like.

'Assessment of pipeline defects detected during pigging operations' one paper from pipeline pigging technology by J.N.H.Tiratsoo gives assessment method for finding significance of defects using simple analytical methods. This summarizes and recommends a methodology for future assessments of corroded pipelines.

'Specifications and requirements for intelligent pig inspection of pipelines', elaborates all kind of tool specifications, characterization, statistical reports etc. List of all codes and standards referred are mentioned in the appendix section.

3. THEORETICAL DEVELOPMENT

3.1.INSPECTION TECHNOLOGIES

In pipelines, magnetic flux leakage (MFL), and ultrasonic testing (UT) are the most usually used technologies for the spotting and sizing of corrosion defects.

3.1.1 MAGNETIC FLUX LEAKAGE TECHNOLOGY

MFL inspection identifies changes in the pipe wall thickness by measuring changes in a magnetic field close to the pipe wall. Magnetic force of attraction between the north and south poles of a magnet is generally represented by drawing 'flux' lines between the poles. These flux lines show the strength and direction of the magnetic field. When a magnet is placed next to a pipe wall, most of the magnetic flux pass through the pipe wall, because the pipe wall is a preferred path for the flux. Flux leakage at a metal loss region is caused by a local decrease in the thickness of the pipe wall. A flux carried by the thinner section is less than that carried in the full cross section of the pipe wall. Sensor positioned on the inside of the pipeline is typically used to record this leakage flux. This can be visualized by different methods. In this manner a MFL tool detects anomaly that causes flux to leak. The measured leakage field depends upon the radial depth, axial length, circumferential width and shape of the anomaly as well as magnetic properties of the material.

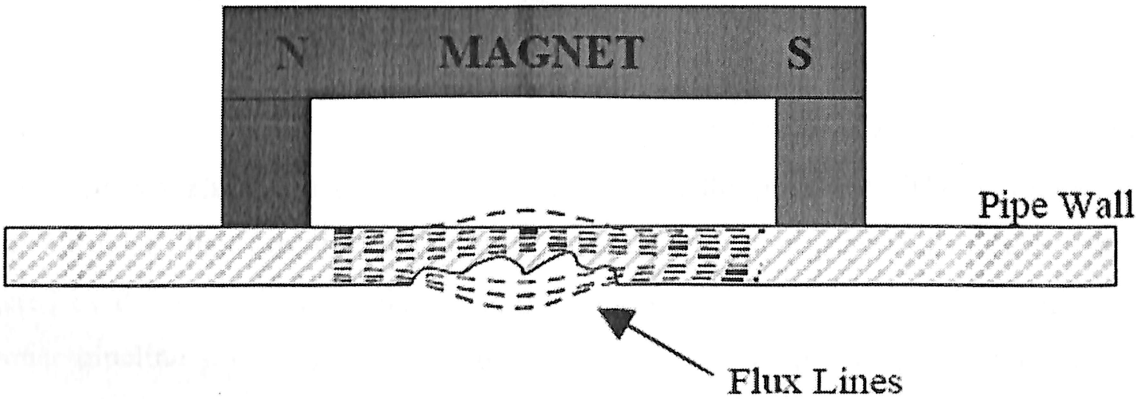


Fig.3.1

To measure the deviations in the magnetic field, sensors are being used. These are either Hall effect sensors or coil sensors. Output signals from these sensors are stored and used to find out the relative depth (to pipe wall thickness), length and width of the corrosion defect. Signals recorded by the tool are can be interpreted by two methods;

- By specially developed softwares
- By an analyst who views the result on screen

3.1.2.ULTRASONIC TECHNOLOGY

Ultrasound is a major nondestructive technology used for range f inspection jobs such as pipelines. Applied principle used for the detection and sizing of metal loss characteristic is given below.

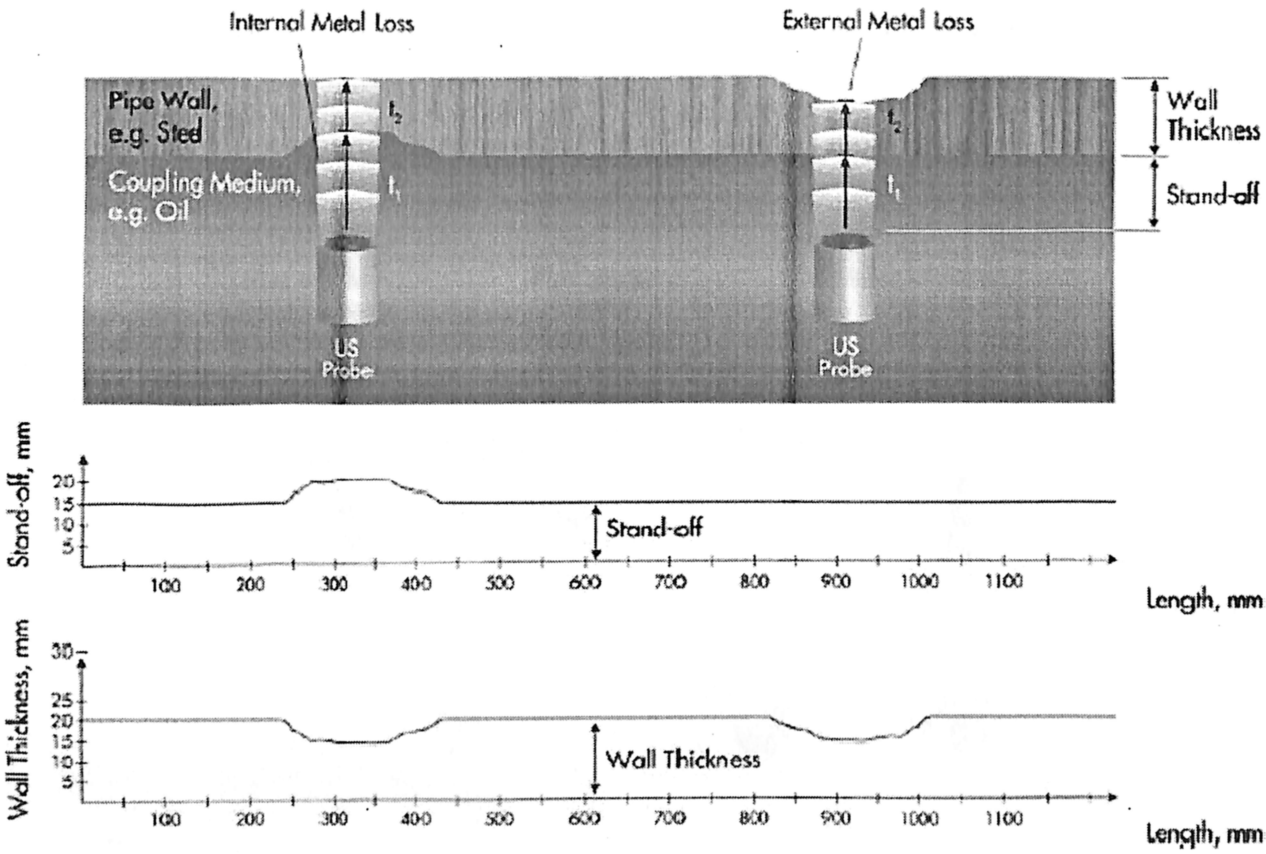


Fig.3.2

Ultrasonic intelligent pigging tool houses transducers which are mounted in a flexible carrier that ensures a proper alignment between each sensor and the pipe wall. These transducers emit high frequency pulses that are reflected from both inner and outer pipe walls. Pulses from the sensor triggered by the transmitter travels across the stand-off distance (e.g.: oil) is partially reflected from the inner pipeline wall surface, and returns to the sensor as the so called entry echo. Remaining sound energy penetrates the pipeline wall is for the major part reflected from the outer pipeline wall surface and returns to the sensor as the so-called rear wall echo.

The distance measured between sensor and pipe wall allows a general statement regarding the location of the corrosion.

- If the distance increases and the wall thickness decreases internal metal loss is indicated.
- If the distance remains unchanged and the wall thickness decreases the defect is located on the outer wall surface.

To avoid invalid time measurements values of stand-off and/or wall thickness which may be caused by multiple reflections, only pulses with a specified time intervals are interpreted by the electronic system.

3.1.3.CALIPER PIGGING (ELECTRONIC GEOMETRY PIGGING) TECHNOLOGY

Caliper tool will be able to locate, measure and characterize the nature of dents and other geometric
anomalies. Caliper tool run is a pre-requisite for intelligent pigging.

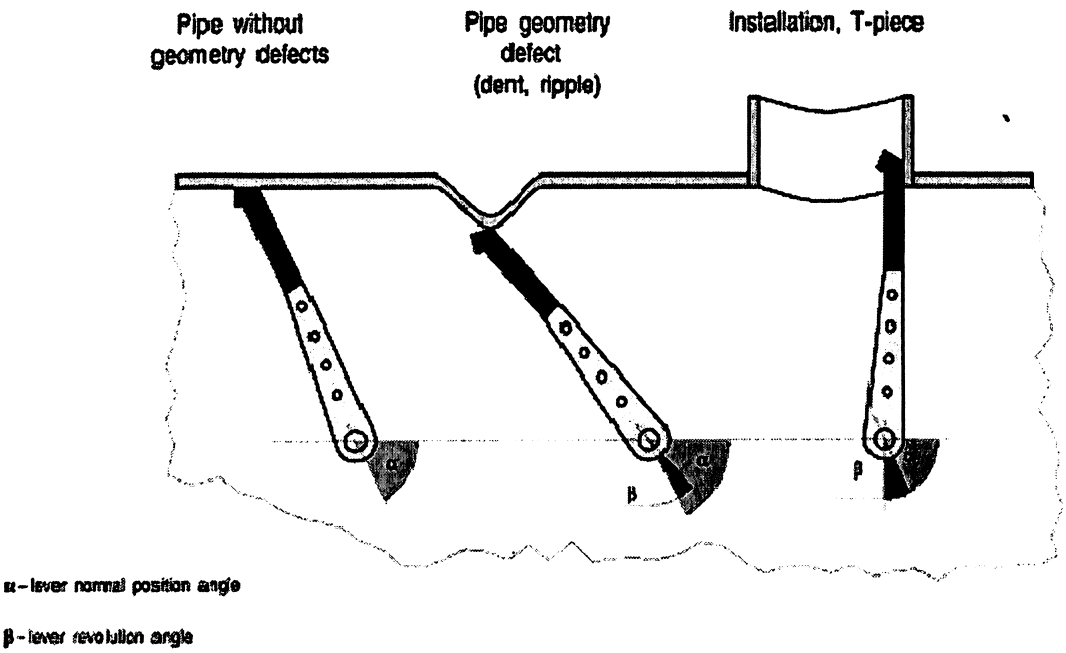
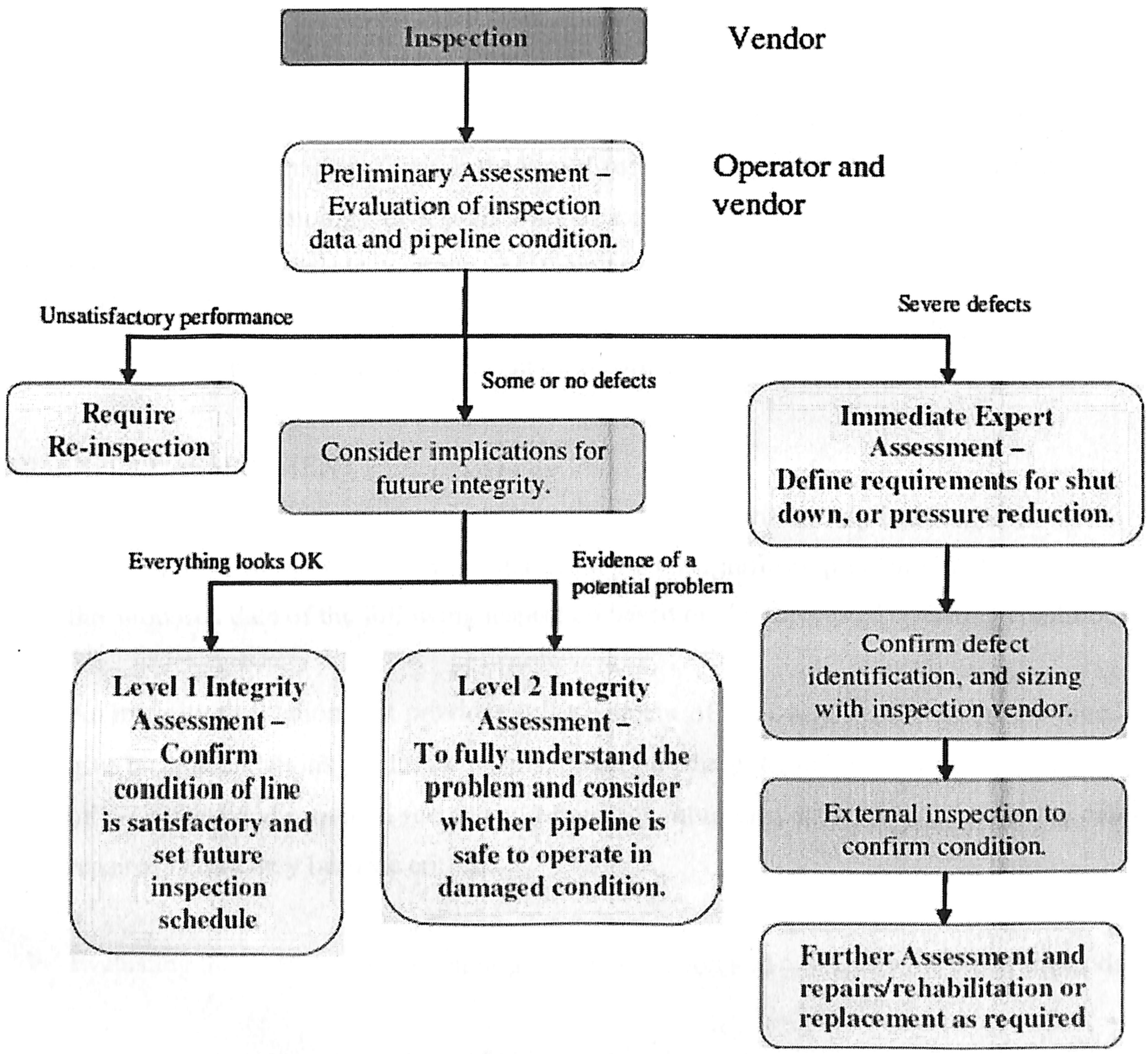


Fig.3.3

3.2.DATA INTERPRETATION

After getting the intelligent inspection data, phases of review and assessment are recommended. A schema of the process is given below.



Assessment of an I.P. result-Fig.3.4

3.3. DATA ASSESSMENT

The first stage of assessing the results of an intelligent pig inspection is of two stages.

- Preliminary assessment
- Expert assessment

3.3.1. PRELIMINARY ASSESSMENT

Preliminary assessment of intelligent pig inspection result is the first stage in which the pipeline operator or data interpreter goes through the issued result. This review does not require a detailed understanding of the technology or a high level of expertise in defect analysis. It only needs an appreciation of pipeline defects, reasons and their significance. It also requires an idea of the capabilities and limitations of the inspection technology. This review is to be carried out by someone with sound experience in integrity management of pipelines.

3.3.2. EXPERT ASSESSMENT

After dealing with the preliminary assessment, some assessment will be required for,

- Basic assessment limited to confirm that there are no significant problems, and setting the proposed date of the following inspection based on the forecasted operating conditions.

- An integrity evaluation that provides an assessment of the overall condition of the pipeline, give recommendations for future repairs, count on the potential growth or degradation rate of the defects and provided recommendations for future inspection to ensure defects can be repaired before they become critical.

- Evaluating the need for shut down or pressure reduction and to identify the repair methods.

- Fitness for purpose assessment:- A 'fitness-for-purpose' assessment calculates the failure condition of a structural defect and compares it with the operating condition of the structure.

4. REVIEW OF DATAS COLLECTED FROM LIVE PIGGING SURVEYS

4.1.ELECTRONIC GEOMETRY PIGGING SURVEY OF DAHEJ-URAN PIPELINE:

Dahej-Uran Pipeline (DUPL) is proposed by GAIL as connectivity to supply gas to consumers like HPCL refinery, TATA power etc. in Mumbai region. This line is a 30 inch dia. line and has a throughput of 4.67 MMSCMD. The caliper tool (EGP tool) inspection of section,ch:280 km to Ch:333 km of DUPL was conducted from 08-06-2007 to 09-06-2007 by M/S Bhotika pipelines services co.pvt.ltd. using 30 inch Analytic Pipe Caliper tool.

4.1.1. GENERAL INFORMATION

Dents affect the safe operation of a pipeline as they restrict the flow of the transported medium and tend to induce spot-like formations of sedimentation, turbulence, erosion corrosion, and hydrates. The pipeline's service life is shortened further by localized excessive mechanical stress. Geometric deviations can be located and their dimensions determined by the Analytic Pipe Caliper-Tool. The Caliper-Tool works during the normal operation of a pipeline and is propelled through the line by the transported medium. The Caliper-Tool is able to pass extreme deformations (up to 25%), the gauging system is of high sensitivity, and the large number of sensing fingers, even the smallest dents can be detected. The data collected during the inspection run are analyzed by means of evaluation software which shows the graphical representation of the inner pipeline diameter. Normally girth welds, wall thickness changes, installations, etc. can be seen on the chart in addition to dents and ovalities.

4.1.2. DESIGN OF THE CALIPER TOOL

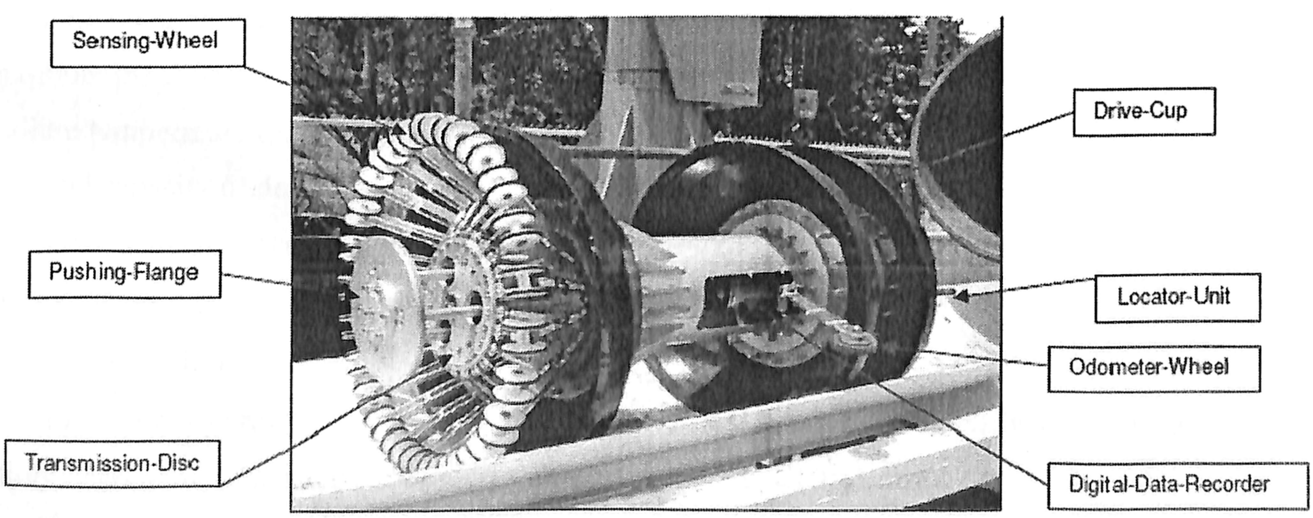


Fig.4.1

The Analytic Pipe Caliper-Tool is an intelligent inspection system which serves to measure diameter reductions in pipelines- such as dents, ovalities, girth welds, wall thickness changes – and to detect T-pieces, valves and other installations.

- The basic body is the central mechanical elements of the Caliper-Tool. All other components are fixed to the basic body.
- The cup sleeves fill the cross section of the pipeline and enable the Caliper-Tool to be transported through the pipeline by the medium.
- The spider measures the inner pipeline diameter at every pipeline position.
- In addition to the measuring data from the spider, the distance data generated by odometer wheels are continuously acquired and stored together with the individual diameter values.
- The internal locator unit transmits electromagnetic signals which allow the Caliper-Tool to be located by an external inspection tool locator.
- The pushing table is used to push the Caliper-Tool into the launcher. Additionally, it helps to fix the calibration ring accurately and to protect the spider against mechanical damage.
- Recorder unit and internal locator unit are contained in pressure-proof steel bodies.

4.1.3. TECHNICAL SPECIFICATIONS

Nominal tool size:	30”
Total length:	1500 mm
Weight:	~ 160 kg
Minimum bend radius:	1,5 X D / 90°
Maximum pipeline pressure:	120 bar
Medium temperature range: -	20° C to +80° C
Type and capacity of data storage:	solid state, 1 GB
Number of sensing fingers:	24
Number of sensing wheels per finger:	2
Diameter of calibration ring:	750 mm
Defect location accuracy:	± 0,5 m (from reference girth weld)
Number and nom. Diameter of odometer wheels:	2 X 105,5 mm
Internal locator unit fitted:	Transmitter

4.1.4. PIPELINE DATA

Outer pipeline diameter (pipeline):	30", 762 mm
Pipeline wall thickness:	10.3, 11.9, 14.3 & 19.1& 22.2 mm
Pipeline length:	~ 53 km
Pipeline product during run:	Compressed Air
Additional information:	Pumping rate ~ 3000 scfm

4.1.5. SURVEY PROCEDURES

4.1.5.1. PIPELINE PREPARATION

Cleaning procedure was preformed with BI-DI pigs inorder to remove debris or deposits which could adversely affect geometry measurement.

4.1.5.2.TOOL PREPARATION

The tool is calibrated by using a calibration ring and simulating dents and ovalities by small calibration blocks. With the help of this calibration, the measurements of the caliper-tool are correlated to the actual ID reductions. Additionally all sensing fingers were calibrated individually. The dent calibration shows 2.5mm steps (beginning with 2.5 mm up to 60 mm), each step of the ovality calibration has an additional value of 5 mm. A calibration of the whole measuring spider was performed. The electronic components were checked both by a system test and a functional test. After having arrived on site, all electronic components were checked by a system test and a recording test. The calibration data were transferred to a laptop.

4.1.5.3. TOOL RUN-MORE DETAILS:

Calibration-Tool run name:	DUPL-30
Caliper-Tool departure:	June 8th 2007; 09:36 hrs
Caliper-Tool arrival:	June 9th 2007; 12:20 hrs.
Pumping rate:	~ 3000 scfm
Type of launcher:	Permanent
Max pressure at launcher:	~ 4.3 bar
Type of receiver:	Temporary
Max pressure at receiver:	~ 3.8 bar
Amount of recorded data:	11,687 kb
Average speed of the Caliper-Tool:	~0.54 m/s
Propelling medium:	Compressed air

4.1.5.4.TOOL HANDLING AFTER THE RUN

After the initial removal, the caliper tool was connected to a laptop. Status check of the electronic unit was performed. Collected data and status data of the caliper tool were transferred to the laptop and quality of the data was assessed.

4.1.5.5. PRELIMINARY INTERPRETATION ON SITE

The chart of the whole run was analyzed. For preliminary interpretation, reductions and ovalities over 5% were searched for by the evaluation software. For the immediate reference/ dig site verification of defect, one maximum sized anomaly i.e., **3.5%** of Pipe I.D. identified & reported.

4.1.5.6. DETAILED EVALUATION OF THE COLLECTED CALIPER-TOOL DATA

The Caliper-Tool data collected during the inspection run were systematically evaluated in the analytic Pipe interpretation department. In order to achieve the required quality of the inspection results, the evaluation of the collected Caliper-Tool data was performed during the several phases:

- Feature Search
- Feature Identification
- Feature Measurement
- Feature Listing
- Cross Check of results

Criteria for features to be entered into the features list(Evaluation thresholds) were:

Ovality-3% of OD

Other reduction-2% of OD

4.1.6. RESULT

Caliper tool data recorded during this inspection clearly depicted the geometrical conditions of the pipeline. Result of some part of the tool run with calibration chart and feature listing is given as follows-Fig.4.2

Analytic Pipe GmbH
Final Report

GAIL 20/06/2007
DUPL(SPREAD III) CH. 280KM-333KM.

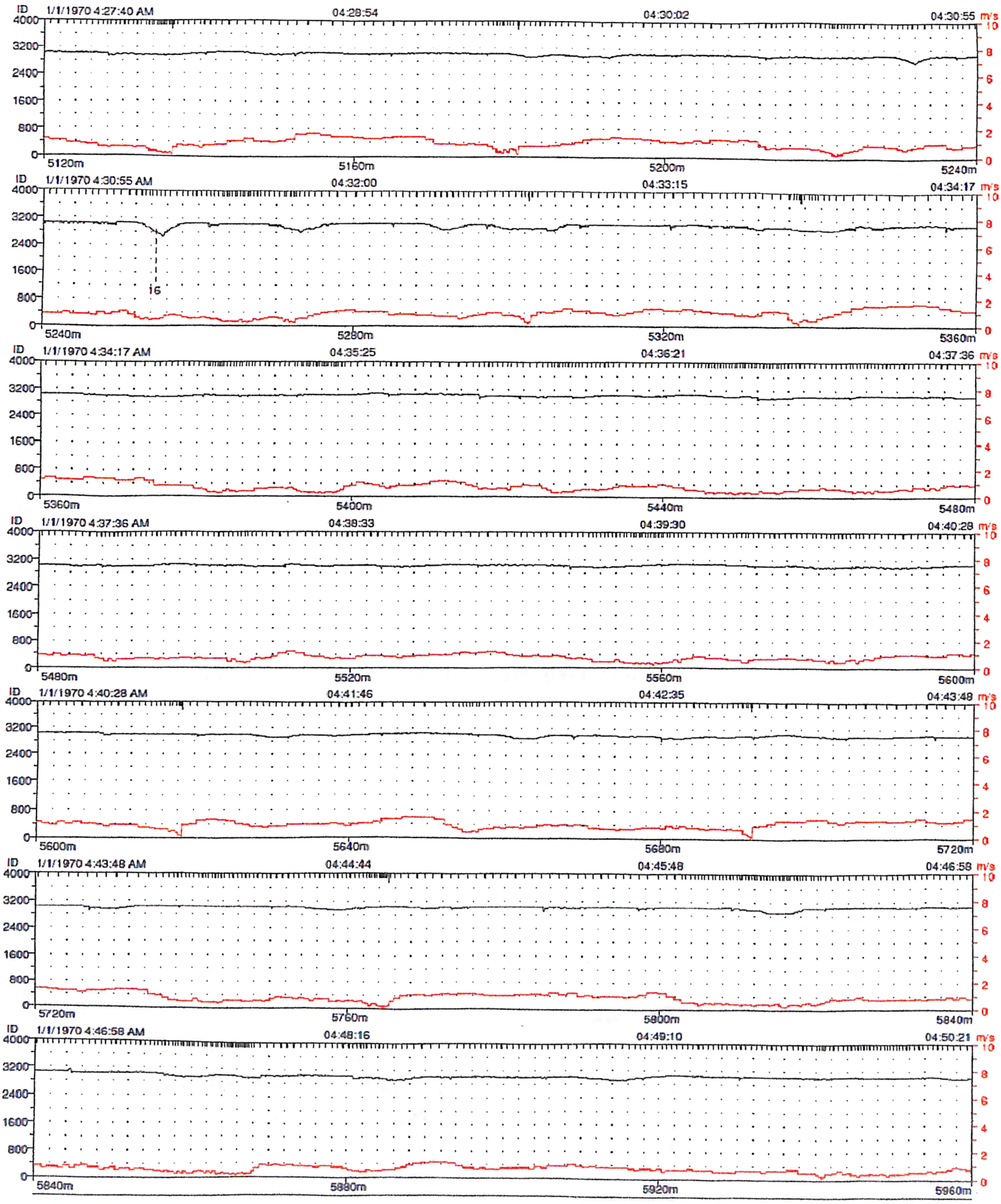


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Fig.4.2

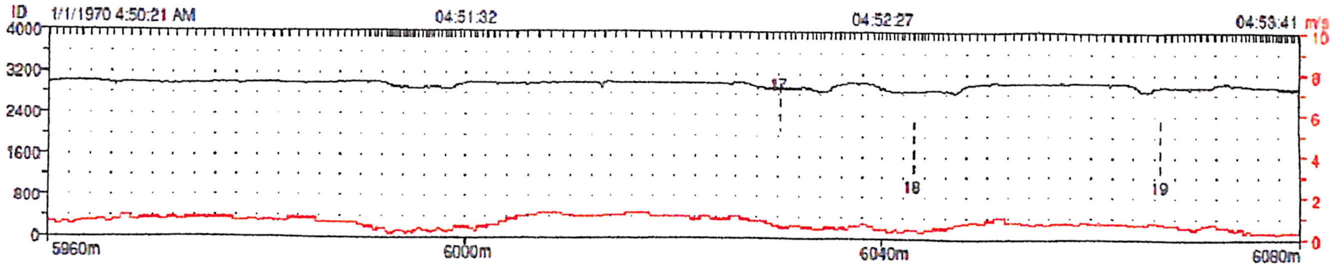
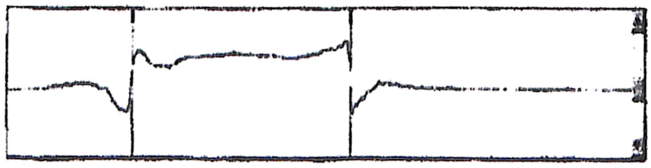


Fig.4.3

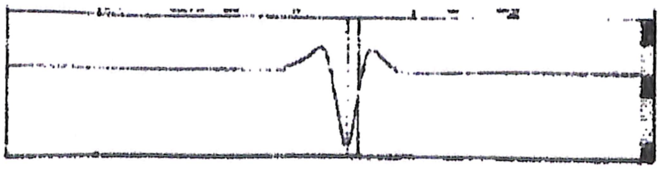
- In above result sheet we can see two plots, internal diameter, and velocity plotted against horizontal distance.
- Horizontal distance covered by the tool is marked for each 40m interval. And the topmost horizontal line gives the time at which the tool reaches the corresponding distance. The bottom line shows the velocity and the top line shows the geometry of pipe.
- In the first section, from 5120m to5240m the top line is steady without any significant change along the distance travelled by the tool.
- In second section, between 5240m and 5280m it gives a sharp change , which can be identified as a dent. The above mentioned dent is marked as 16th.
- In section from 5960m to 6080m feature 18 -19 can be identified as an abnormal condition such as a valve or a heavy wall.

Some guidelines to identify characteristic features are given below:-Fig.4.4

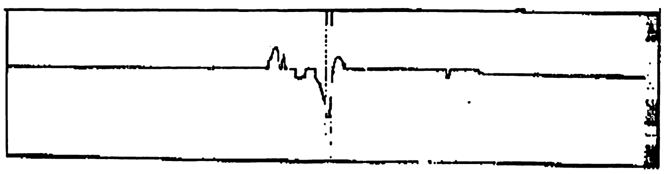
Feature of pipeline fitting



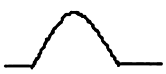
Feature of elbow



External general metal loss



External pitting metal loss

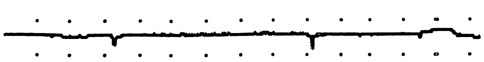


Ovality

Dent

Ovality with dent

Girthwelds



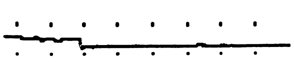


Fig.4.5

Wall thickness changes

While executing a caliper pigging the pressure inside the pipe will be 4 to 5 Kg/cm2. Velocity variations will be visible while moving through a section with elevation change. This falling effect is known as drooping of pig tool. Beneath each sensor, some soft metal will be kept to compromise these kinds of sudden motion causes variations in reading.

4.2. MFL INSPECTION OF VIJAYAWADA-SURYAPET PIPELINE:

Vijayawada-Suryapet pipeline is a section of Vizag-Secundarabad 570Km pipeline owned by HPCL for transporting petroleum products such as high-speed diesel, motor spirit, superior kerosene oil and naphtha from Vizag refinery to different parts of Andhra Pradesh. An intermediate booster cum tap-off station is located at Suryapet. MFL inspection conducted in this line in 2009 August 25th by corrosion detection flux leakage pig by Rosen inspection technologies, Germany.

Details of inspection and inspection data are given below.

The graph obtained is a plot of log(distance) Vs clock position. Each horizontal lines corresponding to clock position represents sensors sensing the flux deviation or leakage. Number of sensors varies depending on accuracy and resolution required. Occasionally some MFL pigs will have 250 to 300 sensors. Here the tool consists of total 81 sensors arranged circumferentially. This lines deviates while approaching any abnormalities such as external/internal metal loss, weld deposition, dents etc. This deviation can be identified by an expert analyst. This MFL tool has two rows of sensors where front row gives external metal loss and the rear row gives internal metal loss. These obtained results will be compared with the datas received from test loop (pipe containing defects of known size and orientation) run conducted priorly to the actual run. Accuracy of the MFL pig used in this inspection is ±10%.

After getting the result of inspection, particular pipes carrying defects are to be identified and excavated for conducting further stages of the assessment process. This will be very difficult activity in case of a cross country pipeline laid over 1000s of kilometers. So magnetic markers are being used for simplifying this job.

Fig.5.6 showing below is an overview plot of VVSP pipeline inspection, in a scale 1:150, from distance 45832m to 45860m.As explained above, each horizontal line shows sensors. And intermittent vertical line is formed by uniform deviation of all sensor line at the same segment, i.e. these lines represent girth welds. It can be observed from the result that these weld metal depositions are almost at same interval and varies slightly depends on the pipe length.

A flat observation cannot detect anything else from Fig.5.6. Here comes the importance of an expert eye who can point out a minute upward deviation of signals in between distance 45+845.2m to 45+845.4m (location of second girth weld in fig.1). It can be visualized clearly from fig.5.7, magnified view of the particular location in a scale 1:5. This sheet is known as detail plot. As discussed in geometry pigging example, according to the sharpness and geometry of the shown deviation, the anomaly can be classified.

Fig.5.8 is a Weld and anomaly location sheet which is used for getting the reference locations .This will be established by placing magnetic markers above pipelines. Permanent reference magnets shall be placed usually at an interval of 1 to 1.5 Km. In this case the distance between reference magnet varies from 205m to 2 Km. Magnets will preferably place at 12'o clock position and MFL tool detects as it passes each of these locations. In fig.3 it can be notice that the weld location is identified with reference to markers. Anomaly location is given on the particular pipe. Latitude, longitude, clock position, length, width, relative depth informations are also given.

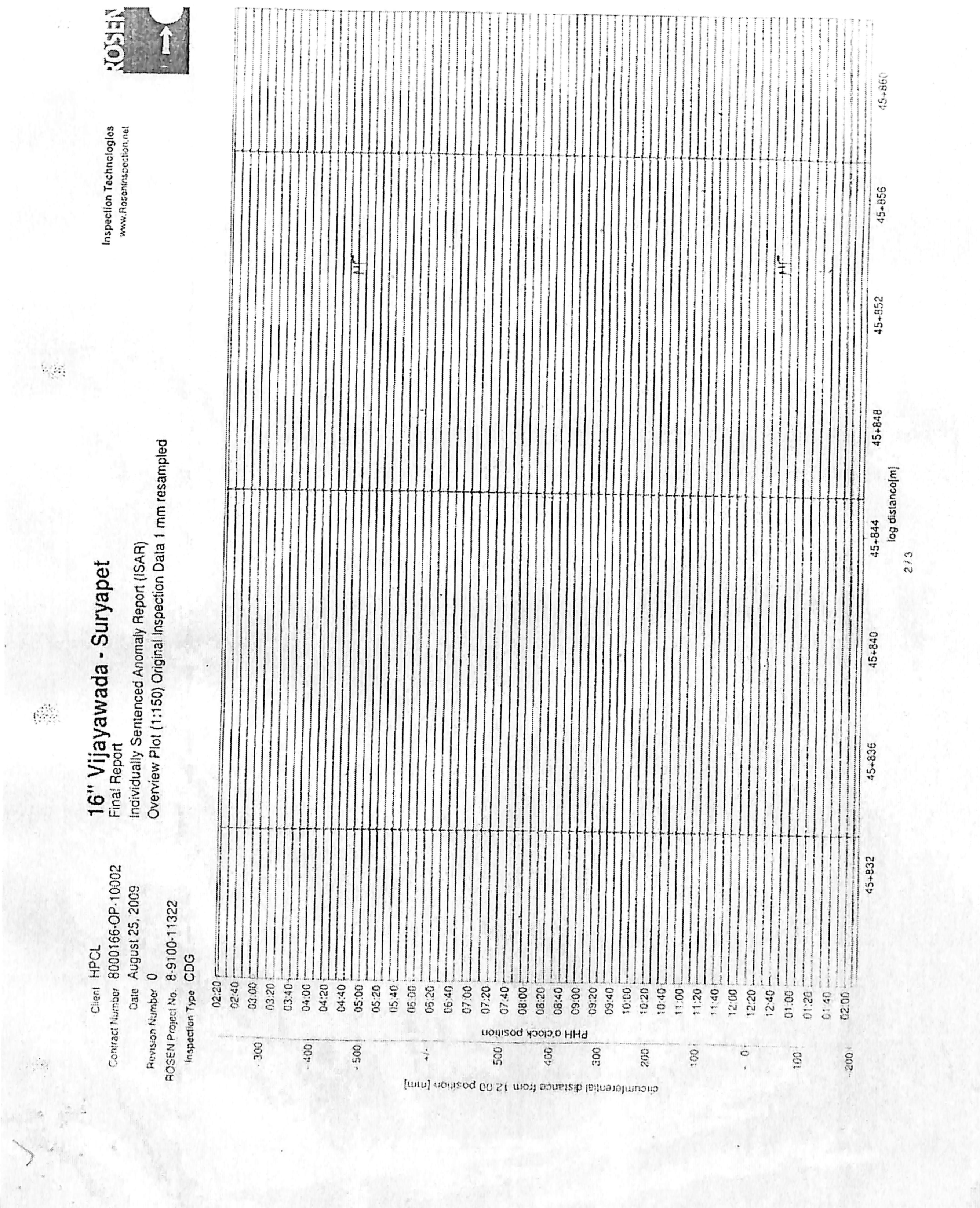


Fig.4.6.Overview plot (1:150)

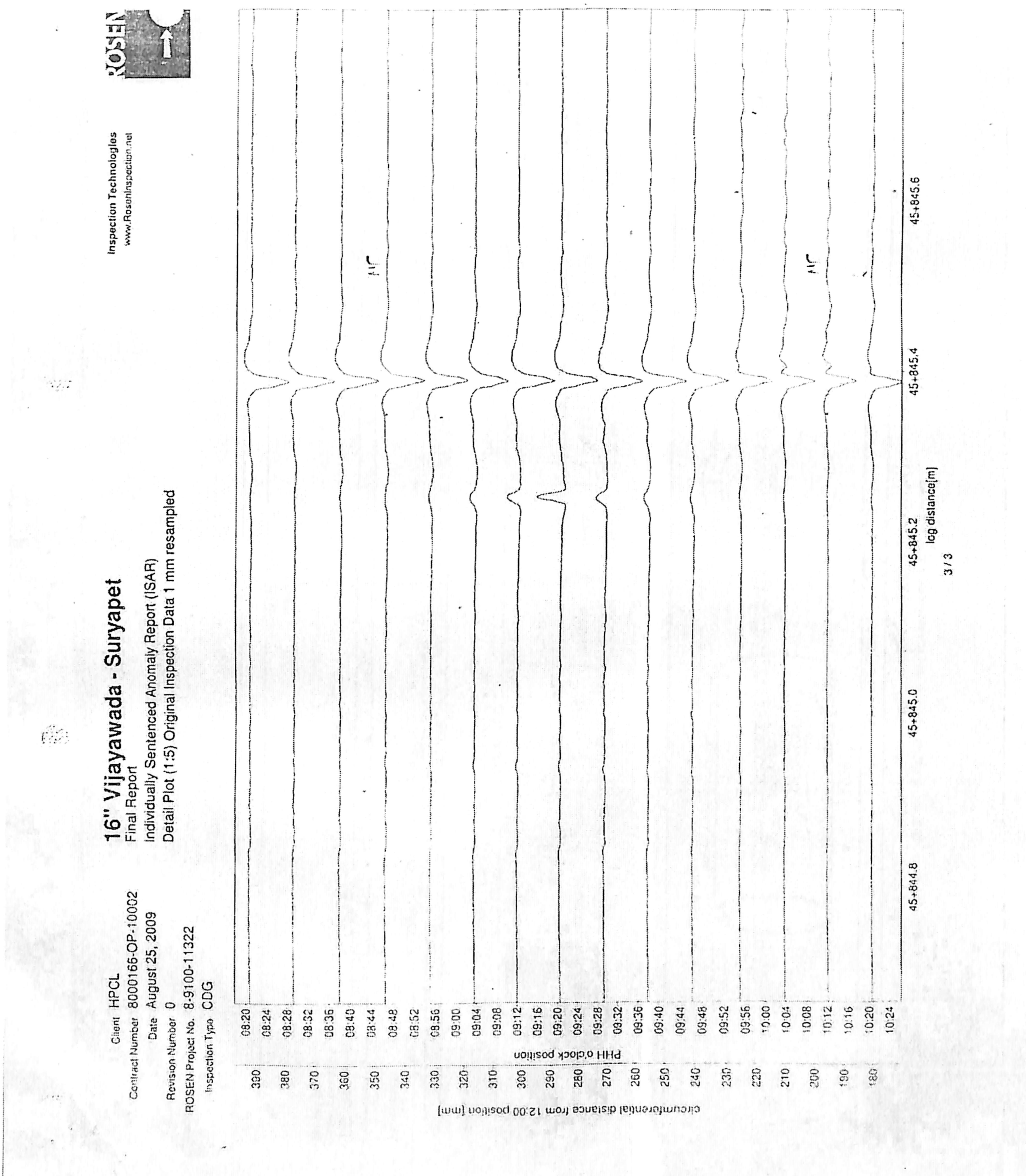


Fig.4.7.Detail plot (1:5)

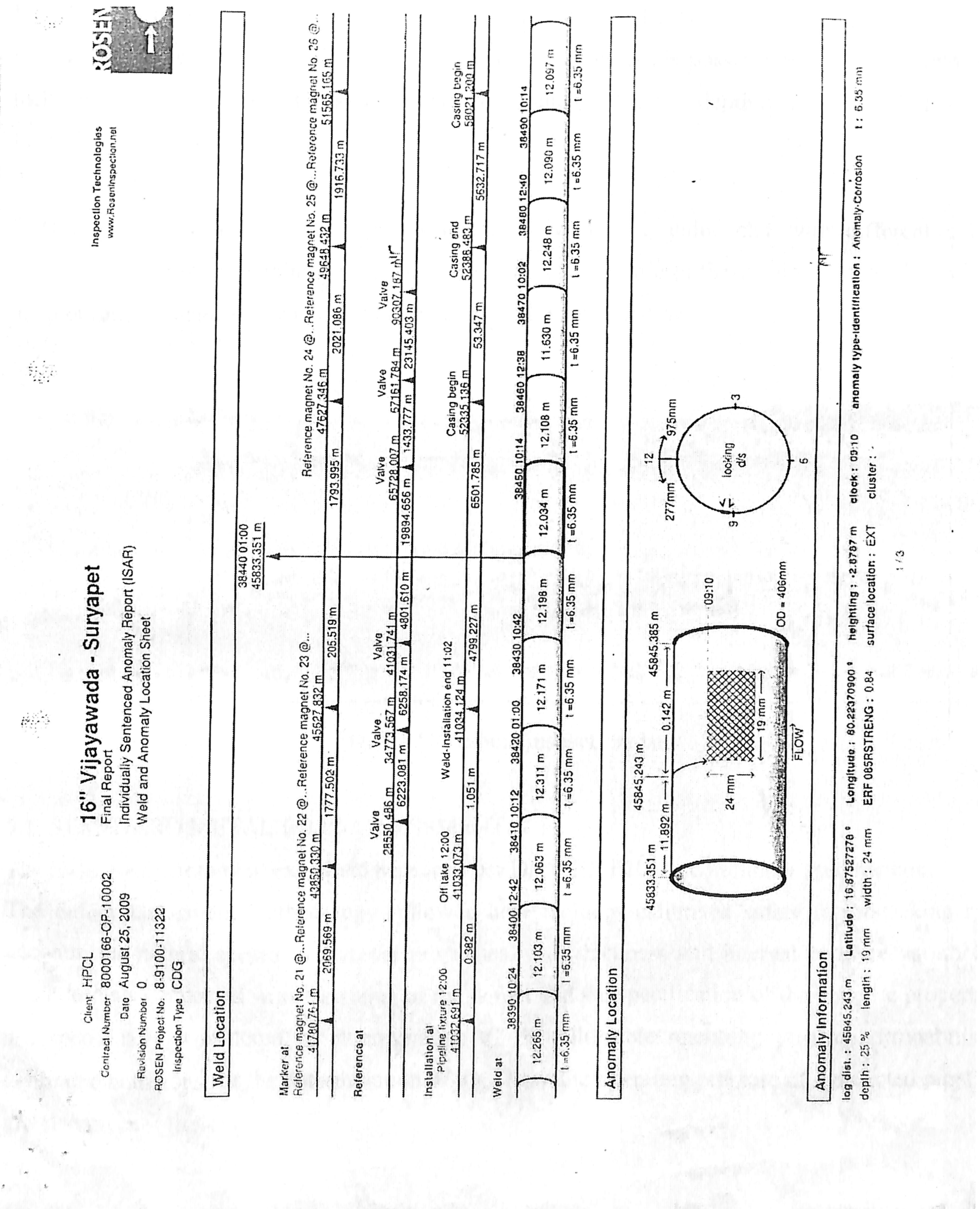


Fig.4.8.Weld and anomaly location sheet

5. DEFECT ASSESSMENT

- MFL data:

Signal output from large no. of sensors recorded and interpreted either automatically or manually by an analyst. The estimation of depth, width and length of defect is possible based on the field that leaks out of the pipe wall. But only relative measurement of defect depth can be made (relative to the pipe wall thickness).

- UT data:

Data collected by an ultrasonic pig is mostly viewed as a color plot with different colors representing different remaining wall thickness. Operator can preset these colors. An analyst views the plots and recognize anomalies to be included in the defect listing.

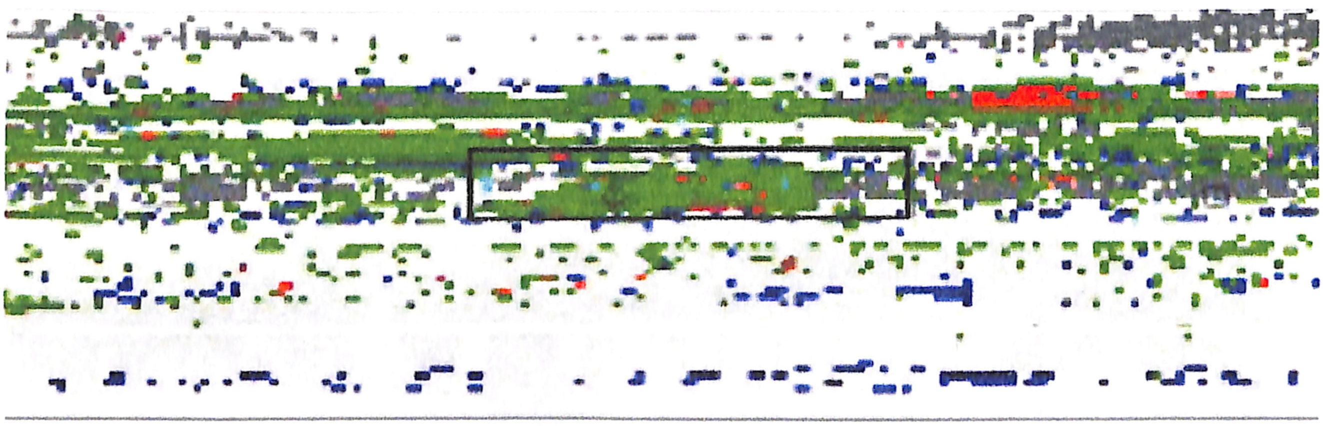


Fig. 5.1 Ultrasonic inspection data

5.1. STANDARD METAL LOSS ASSESSMENT:

The metal loss assessment explained here is as per DNV-RP-F101, a commonly used method.

The defect assessment methodology followed here includes calibrated safety factors taking into account, the natural spread in material properties, wall thickness and internal pressure variations. Uncertainties connected with the sizing of the defect and the specification of the material properties are specifically considered in determination of the allowable operating pressure. Probabilistic calibrated equations for the determination of the allowable operating pressure of a defected pipeline are also given.

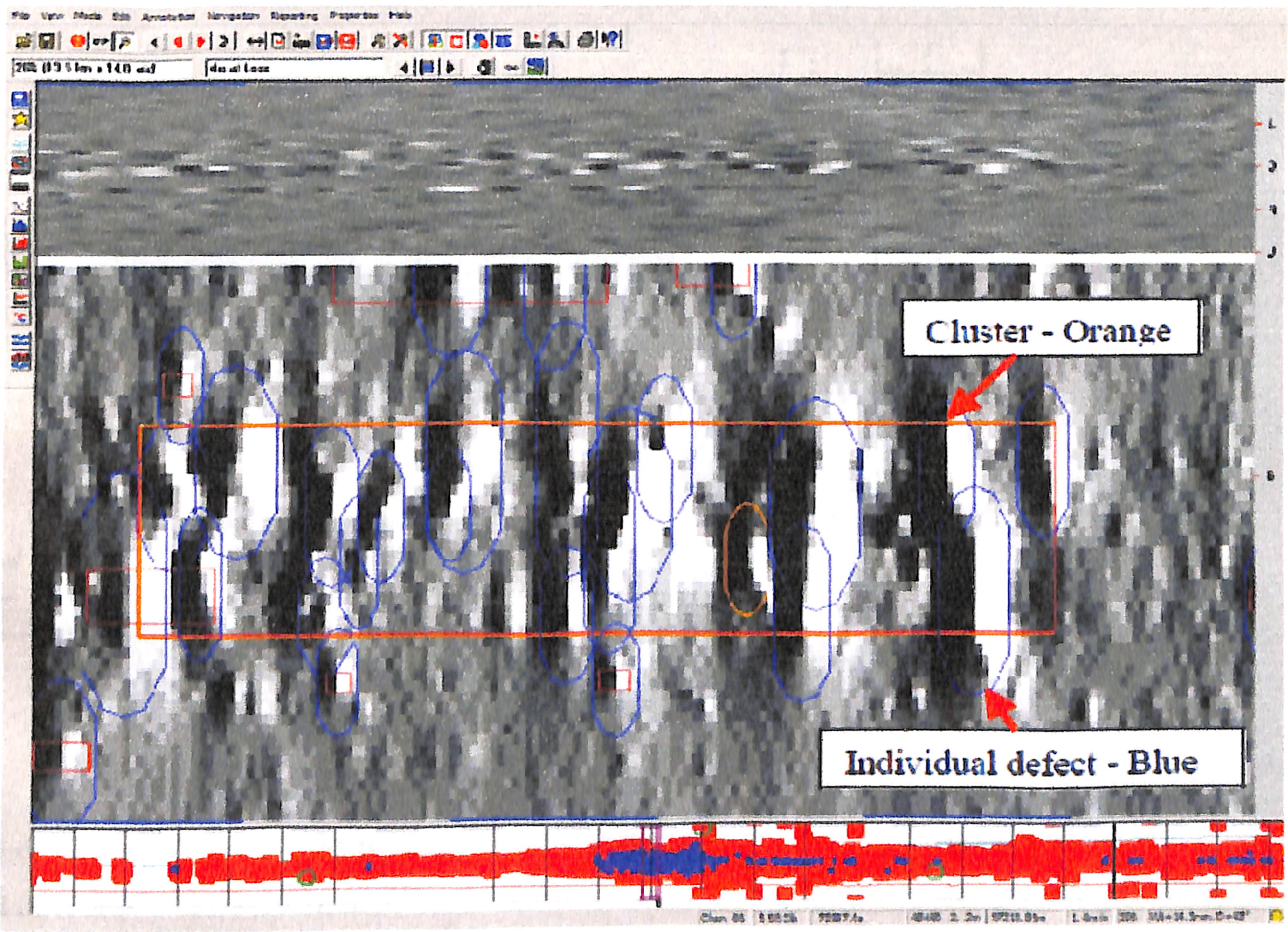
A *Single Defect* is one that does not interact with a neighboring defect. The failure pressure of a single defect is independent of other defects in the pipeline.(Fig.5.3)

An *Interacting Defect* is one that interacts with neighboring defects in an axial or circumferential direction. The failure pressure of an interacting defect is lower than it would be if the interacting defect was a single defect, because of the interaction with neighboring defects.(Fig.8.3)

A *Complex Shaped Defect* is a defect that results from combining colonies of interacting defects, or a single defect for which a profile is available.(Fig.8.4)

5.1.1. Grouping of defects:

When large no. of defects grouped together, it is a clustered defect and for easiness it would be reported as a single defect, with width equal to overall cluster width and depth equal to maximum defect depth.



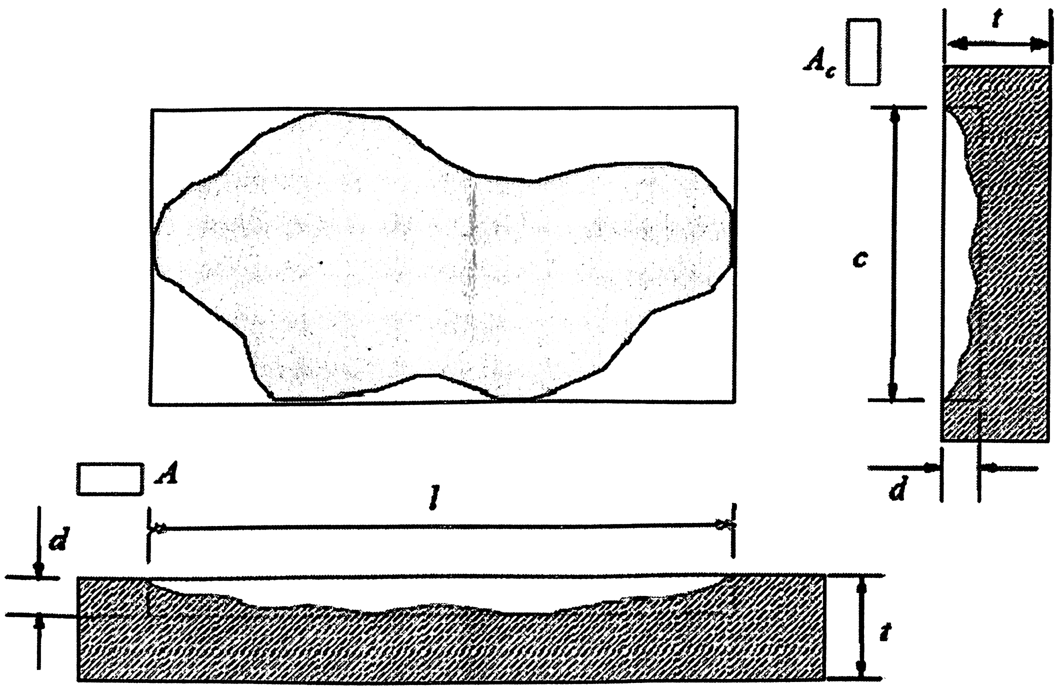
Typical defect grouping-Fig.5.2

DNV method considers corrosion defect as a combination of patch and pits. Pits are deeper portions and patches are general corrosion area. See Appendix II for detailed method of assessing single, interacting, complex types of defects with numerical examples.

5.1.2 Calibrated safety factor:

The approach given here includes calibrated safety factors. Uncertainties associated with the sizing of the defect depth and the properties of the material. are specifically considered. Probabilistic calibrated equations for the determination of the allowable operating pressure of a corroded pipeline are given. These equations are based on the LRFD (Load and Resistance Factor Design methodology. Partial safety factors are given for two general intelligent inspection methods (based on relative measurements. e.g. magnetic flux leakage, and based on absolute measurements e.g. ultrasonic), four different levels of inspection accuracy, and three different reliability levels.

5.2.1. SINGLE DEFECT ASSESSMENT-Ultrasonic pig



Single defect dimensions-Fig.5.3

Outside diameter . = 812.8mm

Wall thickness = 19.1mm

SMTS = 530.9N/mm² (X65)

Defect length (max) = 200mm

Defect depth (max) = 4.8mm (□ 25%)

Maximum allowable operating pressure is 150 bar

Safety class is assumed as Normal

Conf = 80%

StD [*d/t*] = standard deviation of *d/t* = .058 (From table 8.5)

Taking partial safety factors, (Table 8.6)

γ d = 1.22

ε d = 0.49

Using the procedure for assessing single defects,

$$Q = \sqrt{1 + 0.31\left(\frac{1}{\sqrt{Dt}}\right)^2} = 1.3412$$

$$(d\,/\,t)^* = 0.25 + 0.49 \times 0.058 = 0.2546$$

$$p_{corr} = 0.77\frac{2tSMTS}{(D-t)}\frac{(1-1.17(d/t)^*)}{\left(1-\frac{1.17(d/t)^*}{Q}\right)} = 17.40 \text{ N/mm2}$$

The allowable corroded pipe pressure is 17.40 N/mm² (174.0 bar). Therefore, the corrosion defect is acceptable, at the current time, for the maximum allowable operating pressure of 150 bar.

5.2.2. SINGLE DEFECT ASSESSMENT-MFL pig

Outside diameter . = 812.8mm

Wall thickness = 19.1mm

SMTS = 530.9N/mm² (X65)

Defect length (max) = 200mm

Defect depth (max) = 25% of wall thickness

Maximum allowable operating pressure is 150 bar

Safety class is assumed as Normal

StD [*d/t*] = standard deviation of *d/t* =0 .08 (From Table 8.4)

Taking partial safety factors, (Table 8.2 and 8.3)

γ d = 1.28

ε d = 1.0

Using the procedure for assessing single defects,

$$Q = \sqrt{1 + 0.31\left(\frac{1}{\sqrt{Dt}}\right)^2} = 1.3412$$

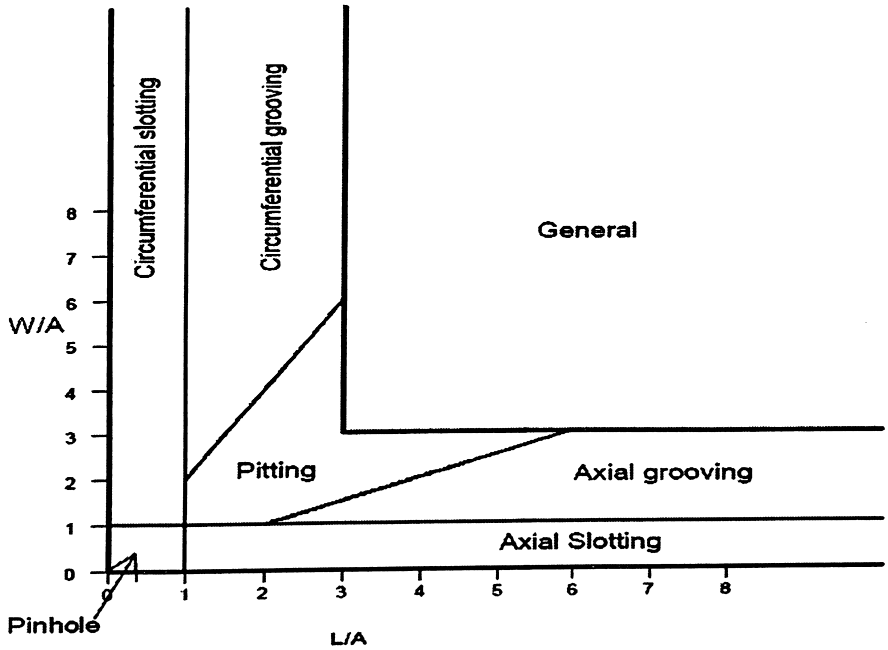
$$(d/t)^* = 0.25 + 1.0\times 0.08 = 0.33$$

$$p_{corr} = 0.74\frac{2tSMTS}{(D-t)}\frac{(1-1.28(d/t)^*)}{\left(1-\frac{1.28(d/t)^*}{Q}\right)} = 15.94 \quad N/mm^2$$

The allowable corroded pipe pressure is 15.94 N/mm² (159.4 bar). Therefore, the corrosion defect is acceptable, at the current time, for the maximum allowable operating pressure of 150 bar.

5.3. CLASSIFICATION ACCORDING TO ANOMALY DIMENSION:

Measurement capacity of a non destructive inspection technology depends on the geometry of the metal loss defect. To allow an exact specification of the measurement capacities of the intelligent pig, these anomaly classifications have been defined as in fig. below. Each class of anomaly class has a range of shapes.



The geometrical parameter A is linked to the NDE methods in the following manner:
If t < 10 mm then A = 10 mm
If t ≥ 10 mm then A = t

Fig.5.4

Anomaly dimension class	Definition	Reference point/size for the POD in terms of L x W
General:	{[W ≥ 3A] and [L ≥ 3A]}	4A x 4A
Pitting:	{([1A ≤ W < 6A] and [1A ≤ L < 6A] and [0.5 < L/W < 2]) and not ([W ≥ 3A] and [L ≥ 3A])}	2A x 2A
Axial grooving:	{[1A ≤ W < 3A] and [L/W ≥ 2]}	4A x 2A
Circumferential grooving.	{[L/W ≤ 0.5] and [1A ≤ L < 3A]}	2A x 4A
Pinhole:	{[0 < W < 1A] and [0 < L < 1A}	½A x ½A
Axial slotting:	{[0 < W < 1A] and [L > 1A]}	2A x ½A
Circumferential slotting:	{[W ≥ 1A] and [0 < L < 1A]}	½A x 2A

Table.5.1

5.4. LOCATING METAL LOSS FEATURES:

After finding out the anomalies in a pipeline by any of the smart pigging technologies, it is necessary to find out the validity of the obtained characteristics before deploying an expensive rehabilitation process. So excavation of the pipe spool is necessary. While locating these defects, it is important that appropriate techniques are being used. For these techniques, see Appendix II.

6. INSPECTION REPORT

A model or an ideal inspection report of a complete survey of ABC pipeline on a 20 inch. oil pipeline by an inspection vendor is given below.

Necessary titles to be included are,

- Inspection summary
- Metal loss feature report
- Comments
- Pressure based pipeline summary report

Pipeline details:

Contract Number:	xxxxxx
Date of Pipeline Commission:	xxxx
Pipeline Outside Diameter:	20 inches nominal
Product :	Oil
Pipeline Length (Client Data) :	4.0km
Pipeline Length (PII Data) :	4.0km
API Grade:	X52
Predominant Pipe Type :	ERW
Previous PII Inspection:	None

6.1. Inspection summary:

- Metal loss:

Total of 1632 metal loss features have been detected on the inspection survey of which the deepest was 75%. These are distributed throughout the pipeline. Approximately 64% of the total number of spools has metal loss reported within them.

- Pipeline anomalies:

Summary of pipeline anomalies detected during the inspection are,

Ferrous metal objects:	5
Eccentric pipeline casings:	1
Dents:	4
Girth weld anomalies:	3
Shell repairs:	1
Patch repaired spools:	5

6.2. Metal loss feature report:

This section provides inspection features for chosen anomalies in detail. The metal loss features are selected for detailed analysis and reporting according to the selection rules as in the specification for the pipeline inspection report .These metal loss characteristics that are reported on inspection sheets have predicted axial lengths, peak depths and location details to the accuracy described in the specifications.

-Summary tables:

This section provides a summary of metal loss features on the inspection sheets.

Insp. Sheet Number	Absolute Distance (metres)	Ext. or Int.	Predicted Dimensions			Pressure Ratio (ERF)	Feature Selection Rule
			Axial (mm)	Circ. (mm)	Depth % WT Peak		
2	367.9	Int	61	527	75	1.010	1
4	3265.1	Int	194	37	26	1.000	5
3	3618.9	Int	273	59	23	1.010	4
5	3761.7	Int	89	828	42	0.980	5
1	3806.1	Int	289	163	38	1.100	1

Table.6.1

-Inspection sheets:

This section provides detailed inspection sheets for chosen metal loss features. Each sheet contains three main areas, feature description, feature location, schematic location summary.

Feature Description

Type:	Internal Metal Loss
Orientation:	05:00 (o'clock)
Axial length:	61 mm
Circumferential width:	527 mm
Depth - Peak:	75% WT
Pressure Ratio (ERF):	1.010
Feature Selection Rule:	1
Nominal Pipe wall thickness for spool:	20.00 mm
Absolute Distance from Launch:	367.9 metres

Comments:

This isolated metal loss feature is characteristic of corrosion.
This is the deepest metal loss feature within the pipeline.

Feature Location

Primary Reference/s:

1. OFFTAKE-SPHERE-TEE
   (Girth Weld 7 + 0m)

2. MAGNET
   (Girth Weld 760 + 5.1m)

Reference Girth Weld:

The reference girth weld at the Launch (upstream) end of the feature spool is number 570.
The location of this weld is 363.0 metres downstream from reference 1 and 236.2 metres upstream from reference 2.

Feature:

The feature is located 0.0 metres downstream from the reference girth weld.

Schematic Location Summary:

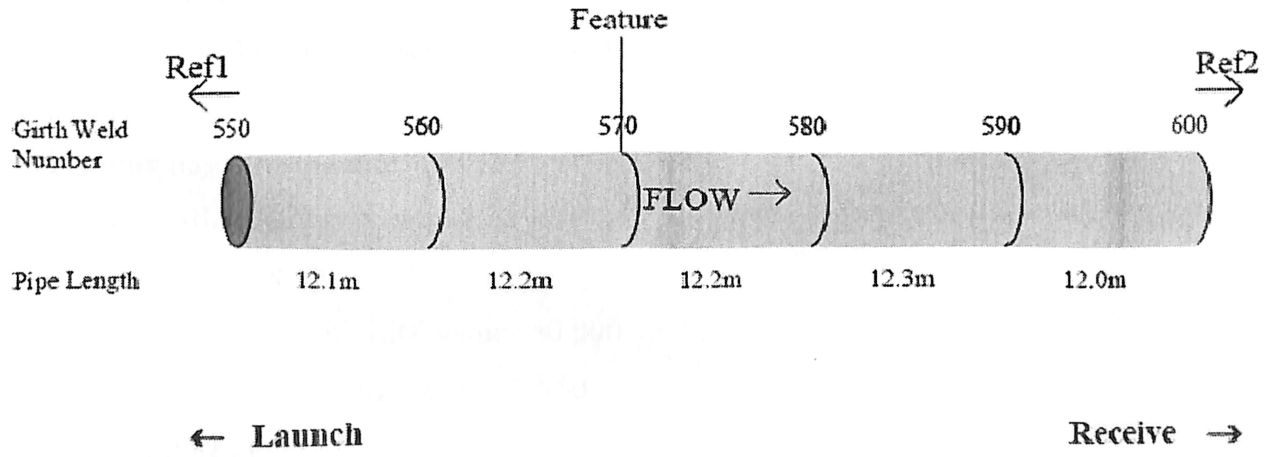


Fig.6.1

6.3. Overall comments:

This section provides any significant detrimental features if any. In this situation, the pipeline operator could consider monitoring the future condition of the pipeline, with planning of further inspections.

6.4. Pressure based pipeline survey report:

This section provides summaries of all metal loss characteristics detected throughout the length of the pipeline in the following formats.

- Pressure Sentenced Plot
- Pressure Based Histograms
- Depth Based Histograms
- Orientation Plot
- Severity Table

6.4.1. Pressure sentenced plot:

Relative significance of each metal loss feature detected can obtain from pressure sentenced plot. Manufacturing defects are not reflected by pressure sentenced plot. Using ASME B.31G these features can be identified.

By plotting the predicted peak depth of the metal loss feature against its predicted axial length and by indicating on the graph the appropriate curve, that represents an ERF of 1, the pressure sentenced plot gives the relative significance of each metal loss feature. The ERF curve moves if any of the values for D, nwt, MAOP or Pi change. Those metal loss features with ERF values >1 will be plotted above the curve. Higher the value, higher the significance and the further away from the curve the metal loss feature will be plotted. If the pipeline segment does not contain any significant metal loss feature , the pressure sentenced plot will not be provided.

See Appendix –III.1

6.4.2. Pressure based histogram:

See Appendix –III.2

Summarizing the histogram:

1622 metal loss features with ERF values >0.900

13 metal loss features with ERF values >0.950

4 metal loss features with ERF values >1.

6.4.3. Depth based histogram:

A three dimensional summary histogram

See Appendix –III.3

Features are classified into nine depth categories and are displayed on a single three dimensional graph. Each bar represents the number of metal loss features within the suitable depth category for a specific section of the pipeline.

6.4.4. Orientation plot:

See Appendix- III.4

Orientation plot shows the location and intensity of every metal loss features around the circumference of the pipe. It is a plot, of absolute distance from the launch Vs orientation of the metal loss. For every metal loss feature a box is drawn on the plot demonstrating the predicted circumferential and axial extent of the metal loss feature. Due to the scale along the distance axis, each metal loss feature appears as a solid vertical line on the plot.

6.4.5. Severity table:

See Appendix III.5

Pipe spools which comprise most severe metal loss features can be identified by severity table. Manufacturing defects are not included in this table. Worst metal loss defects are only considered and are listed in severity order.ERF value changes between 0.5 and 2.0.

6.4.6. Pipeline information:

The pipeline Information gives summaries of pipeline anomalies, repairs, location reference points and changes in the nominal pipe wall thickness along the pipeline. The following summaries are provided.

- Velocity plot
- Metal object report
- Eccentric casing report
- Dent report
- Girth weld anomaly report
- Repair listing
- Location general point listing
- Nominal wall thickness listing

6.4.7. Pipeline listing:

This section gives the sequence of girth welds, metal loss features, metal objects, eccentric pipeline casings, dents, girth weld anomalies and repairs detected from the pipeline. Location reference points and changes in the nominal pipe wall thickness are also included in the pipeline listing.

Launch to Receive

Girth Weld Number	Relative Distance (metres)	Absolute Distance (metres)	Comment	Peak Depth	Length	ERF	Orientatior (hrs:mins)
1	0.0	0.0					
2	1.2	1.2					
			VAI VF				
3	0.8	2.0					
4	0.5	2.5					
5	0.1	2.6					
6	0.5	3.1					
			Blinkety Blonk				
7	1.8	4.9					
			OFFTAKE-SPHERE-TEE				
8	0.9	5.8					
9	4.1	9.9					
10	3.0	12.9					
			Blinkety Blonk				
20	1.4	14.3					
	1.8	16.1	INT MFG	9%	61		05:15
	2.3	16.6	INT MFG	7%	56		01:30
	2.7	17.0	INT MFG	9%	44		05:45
	3.6	17.9	INT MFG	6%	62		05:30
30	4.3	18.6					
			BEND-FORGED RIGHT				
40	4.1	22.7					
50	2.4	25.1					
			BEND-FORGED RIGHT				
60	2.0	27.1					
	0.9	28.0	REPAIRED SPOOL				
70	4.7	31.8					
			BEND-FORGED OVER				
80	1.9	33.7					
90	1.6	35.3					
100	8.1	43.4					
110	8.2	51.6					
120	8.1	59.7					
	0.0	59.7	INT MFG	25%	25		04:15
	1.2	60.9	INT MFG	10%	32		01:45
130	8.1	67.8					
	6.3	74.1	INT MFG	13%	42		02:45
140	8.1	76.9					
	4.6	80.5	REPAIR-PATCH				06:00
	6.2	82.1	INT MFG	10%	25		12:30
	6.9	82.8	INT MFG	4%	22		02:45
	7.1	83.0	INT MFG	16%	30		03.30
150	8.2	84.1					
	3.5	87.6	INT ML	11%	40	0.910	10:15

Table.6.2

7. CONCLUSION

Provided a process for assessing the set of intelligent pig inspection data with reference to industry standards. A sample inspection sheet is provided for better understanding of what to and what not to include in the result sheet. Detailed datas collected from live experiments conducted in oil and gas pipelines in India are elaborated in detail, with numerical examples for assessment of defect. For more honest outturn of smart pigging it has to be combined with faultless phases of assessment.

8. APPENDIX

APPENDIX I

Reliability levels:

Design of a pipeline normally based on location/safety class. Category of fluid and failure consequence for each mode of failure to be classified into safety classes.

Safety Class	*Indicating a target annual failure probability of:*
High	$< 10^{-5}$
Normal	$< 10^{-4}$
Low	$< 10^{-3}$

Safety class and target annual failure probability for Ultimate Limit State (ULS)-Table 8.1

Subsea oil and gas pipelines will be normally classified as safety class normal. Water injection pipelines can be considered for safety class low. Risers and pipeline parts close to platforms are safety class high.

Partial safety factors and fractile values:

The partial safety factors are given as functions of the sizing accuracy of the calculated defect depth for inspections based on relative depth measurements and for inspections based on absolute depth. For inspections based on relative depth measurements the accuracy is normally cited as a fraction of the wall thickness. For examination based on absolute depth measurements the accuracy is normally quoted directly. An appropriate sizing accuracy should be selected in consultation with the inspection tool provider. The acceptance equation is based on two partial safety factors and subsequent fractile levels for the characteristic values.

γm = Partial safety factor for model prediction.

γd = Partial safety factor for corrosion depth.

εd = Factor for defining a fractile value for the corrosion depth.

StD[d/t] = Standard deviation of the measured (d/t) ratio (based on the specification of the tool).

Safety factors can be find out based on,

- Safety class
- Inspection method(Relative/Absolute)
- Inspection accuracy and confidence level

Inspection method	*Safety Class*		
	Low	*Normal*	*High*
Relative (e.g. MFL)	$\gamma_m = 0.79$	$\gamma_m = 0.74$	$\gamma_m = 0.70$
Absolute (e.g. UT)	$\gamma_m = 0.82$	$\gamma_m = 0.77$	$\gamma_m = 0.72$

Partial safety factor γ_m (Table 8.2)

Table 3-7 Partial safety factor and fractile value				
Inspection sizing accuracy, StD[d/t]	ε_d	*Safety Class*		
		Low	*Normal*	*High*
(exact) 0.00	0.0	$\gamma_d = 1.00$	$\gamma_d = 1.00$	$\gamma_d = 1.00$
0.04	0.0	$\gamma_d = 1.16$	$\gamma_d = 1.16$	$\gamma_d = 1.16$
0.08	1.0	$\gamma_d = 1.20$	$\gamma_d = 1.28$	$\gamma_d = 1.32$
0.16	2.0	$\gamma_d = 1.20$	$\gamma_d = 1.38$	$\gamma_d = 1.58$

Partial safety factor and fractile value(Table 8.3)

StD (d/t) for relative (MFL):

The approach to calculate the standard deviation StD[d/t] where a Normal distribution is assumed is:

StD[d/t] = acc_rel/NORMSINV(0.5 + conf/2)

acc_rel = the relative depth accuracy, e.g. 0.2 (0.2 t)

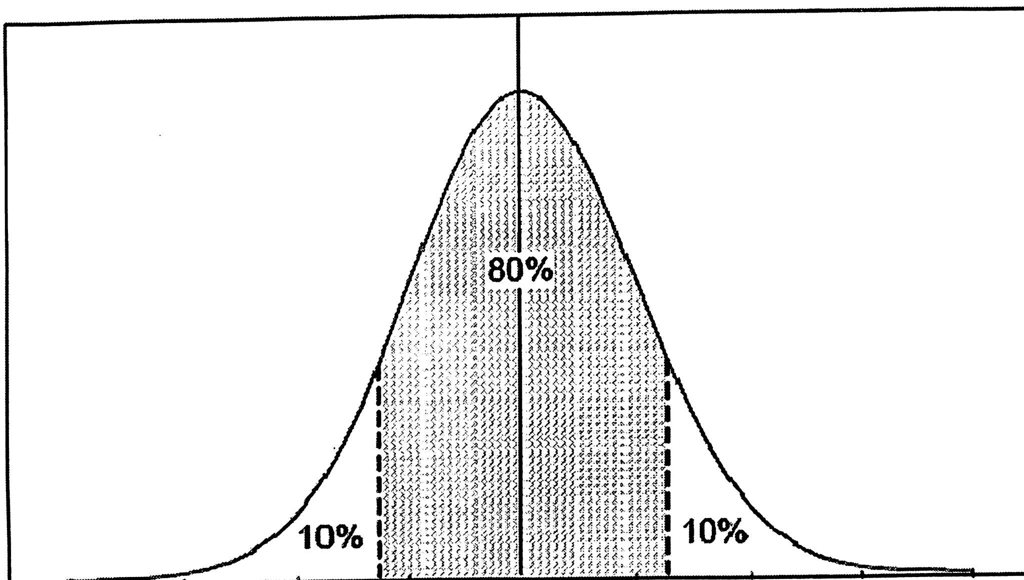
conf = the confidence level, e.g. 0.8 (80%)

- NORMSINV = a Microsoft Excel function. NORMSINV(x) returns the inverse of the standard normal cumulative distribution at probability x.
- The confidence level indicates the portion of the measurements that will fall within the given sizing accuracy.

A selected set of calculated standard deviations for relative sizing accuracy is given below(Table 8.4)

Relative sizing accuracy	*Confidence level*	
	80% (0.80)	*90% (0.90)*
Exact ± (0. 0 of t)	StD[d/t] = 0.00	StD[d/t] = 0.00
± 0.05 of t	StD[d/t] = 0.04	StD[d/t] = 0.03
± 0.10 of t	StD[d/t] = 0.08	StD[d/t] = 0.06
± 0.20 of t	StD[d/t] = 0.16	StD[d/t] = 0.12

Fig. given below gives sizing accuracy of ±5% of t, quoted with a confidence level of 80%.-(Fig.8.1)



StD[d/t] for absolute (e.g. UT):

StD[d/t] = acc_abs/(t · NORMSINV(0.5 + conf/2))

acc_abs = the absolute depth accuracy, e.g. 0.5 (0.5 mm)

conf = the confidence level, e.g. 0.8 (80%)

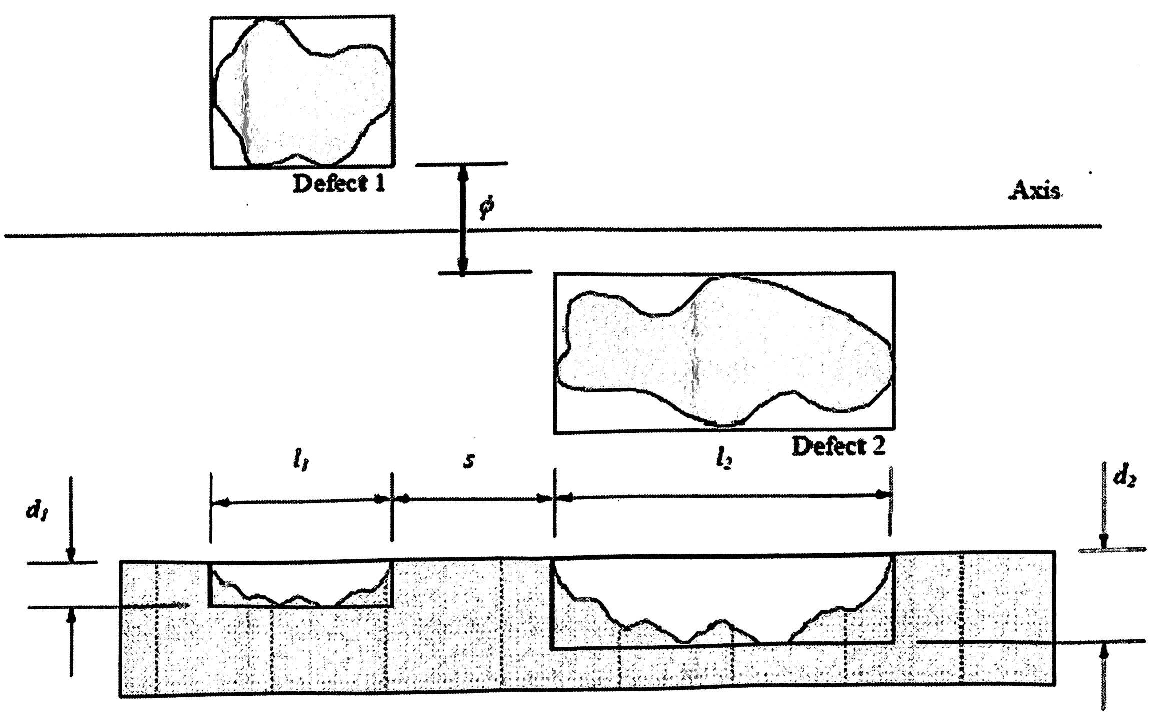
Table 3-6 Standard deviation and confidence level, t =19.05 mm

Absolute sizing accuracy	*Confidence level*	
	80% (0.80)	*90% (0.90)*
Exact ± (0 mm)	StD[d/t] – 0.000	StD[d/t] – 0.000
± 0.25 mm	StD[d/t] = 0.014	StD[d/t] = 0.011
± 0.5 mm	StD[d/t] = 0.029	StD[d/t] = 0.023
± 1.0 mm	StD[d/t] = 0.058	StD[d/t] = 0.045

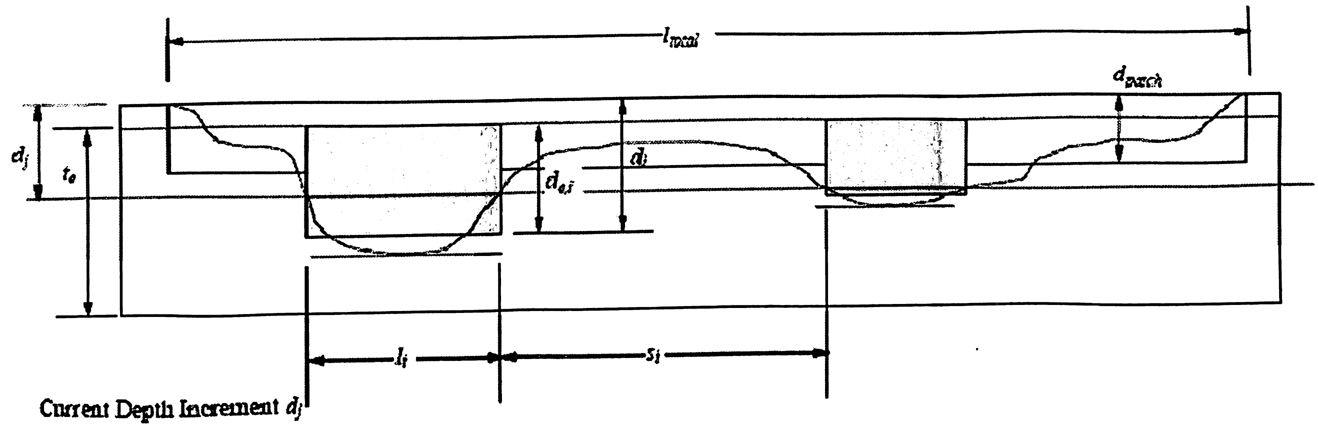
Table-8.5

Table 3-8 Polynomial Equations for Partial Safety Factor and Fractile Value, see Table 3-7 Substitute "a" with "StD[d/t]"		
Safety Class	γ_d *and* ε_d	*Range*
Low	$\gamma_d = 1.0 + 4.0\,a$	$a < 0.04$
	$\gamma_d = 1 + 5.5a - 37.5a^2$	$0.04 \leq a < 0.08$
	$\gamma_d = 1.2$	$0.08 \leq a \leq 0.16$
Normal	$\gamma_d = 1 + 4.6a - 13.9a^2$	$a \leq 0.16$
High	$\gamma_d = 1 + 4.3a - 4.1a^2$	$a \leq 0.16$
(all)	$\varepsilon_d = 0$	$a \leq 0.04$
	$\varepsilon_d = -1.33 + 37.5a - 104.2a^2$	$0.04 < a \leq 0.16$

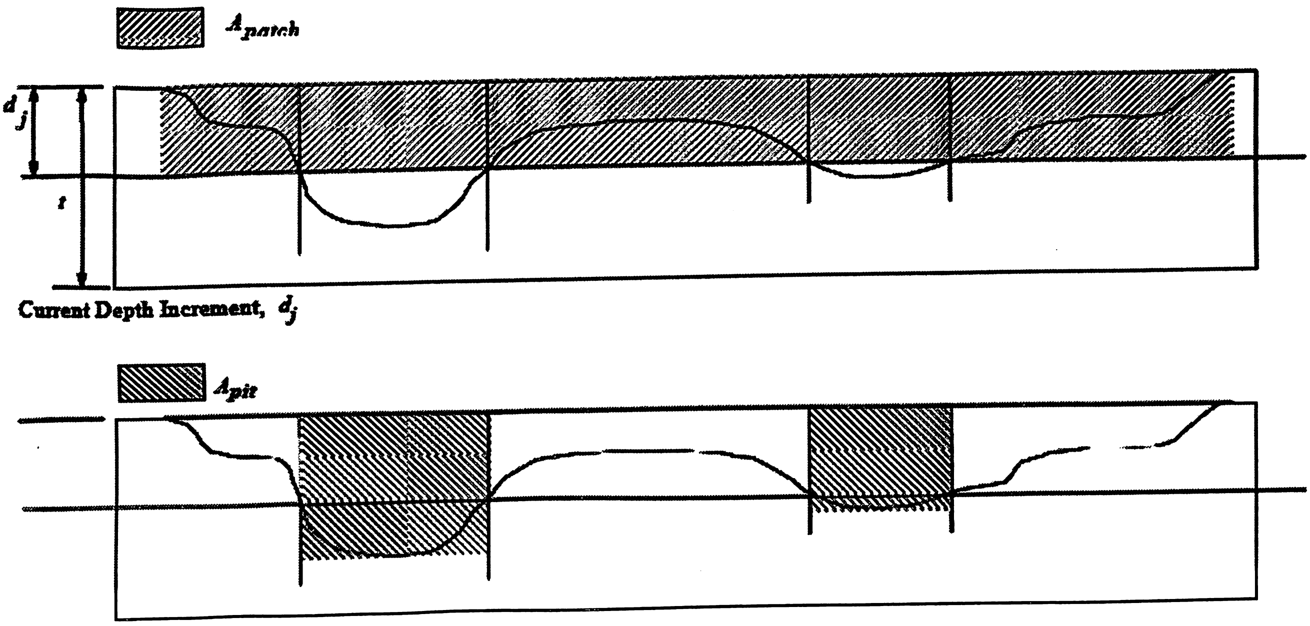
Table-8.6



Interacting defect dimension-Fig 8.2



Complex shaped defect Fig-8.3



subdivision of complex shape into idealised 'patch' and 'pits'-Fig.8.4

APPENDIX II

LOCATION OF FEATURE:

For identification of each metal loss at least one reference point is to mentioned. These reference points are usually fittings like mainline valves, offtakes, anodes, bends etc.

Locating a feature will be of two stages, locating the spool and locating the feature inside the spool. To locate the anomaly on a spool, distance from the upstream girth weld to the feature and the location of the feature around the circumference of the pipe, as watched in the direction of flow, are provided. These distances can be measure out using electronic distance measuring equipment (EDM) to an accuracy of ±1%.

Metal loss, girth weld anomalies, dents will require an area of the protective wrap to be removed.

A minimum area of 0.6m along the pipe axis by 45° of the circumference, centered on the reported feature position, should be cleaned back to bare metal. Once it is done, any external metal loss, dents or the girth weld that contains an anomaly should be easily discovered. On the outside surface of pipe, the position of internal metal loss should be marked in preparation for further examination. By running one's hand along the pipe surface or by placing a straight edge along the pipe shallow dents can be identified.

Actions to be performed as part of this inspection are,

1) Pipe surface preparation:

To achieve satisfactory For accurate recording and measurement of a feature it is essential that particular specified area of pipe surface is cleaned back to bare bright metal.

There are a number of methods for removing pipe wrap primer including:

(a) Solvent cleaning.
(b) Chemical cleaning.
(c) Wire brushing.
(d) Grit blasting.

2) External metal loss area mapping:

- Rubbing

This is done by placing a paper sheet over the defect and hold it firmly and rubbing the long edge of a wax crayon over paper surface. The edges of the feature will be delineated and can be highlighted.

Feature identity, flow direction, orientation, distance from nearest girth weld are to be annotated on the paper.

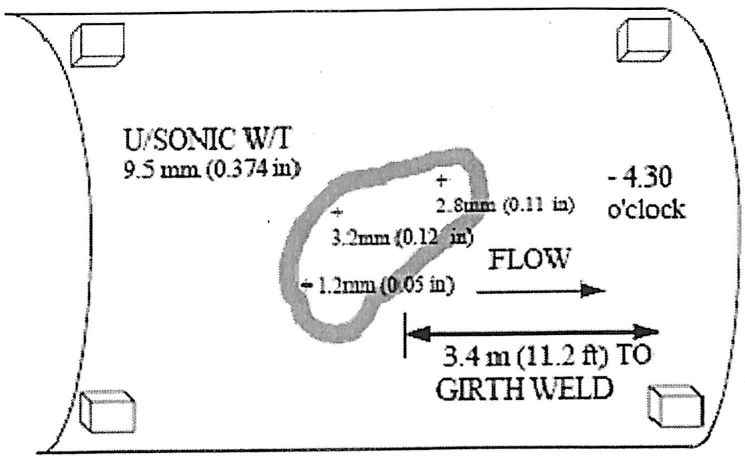


Fig.8.5

3) External metal loss depth recording:

One of the most effective method for registering external metal loss depth is by using a depth micrometer in connection with a large bridging bar. micrometer anvil be ground to a taper with a tip diameter of approximately 1.0mm. This will enable entry into the small diameter pitting and concave surfaces found at the bottom of most metal loss features. A depth micrometer has a resolution of better than 0.05mm.

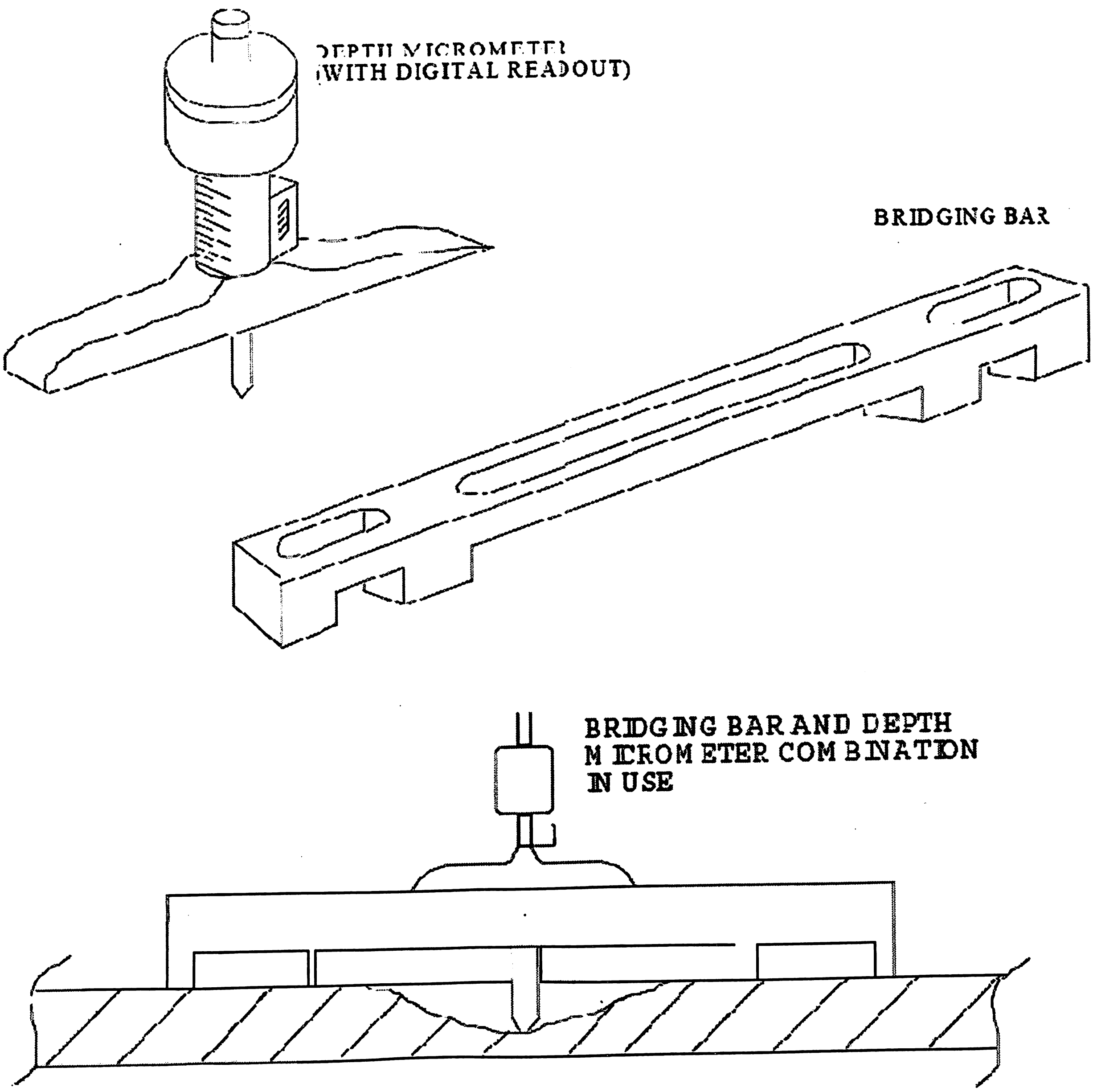


Fig.8.6

4) Wall thickness and remaining ligament thickness recording:

Wall thickness and remaining ligament thickness of damage can be calculated to an accuracy of ±0.05% mm using standard ultrasonic wall thickness meters. While measuring remaining ligament thickness, extreme care should taken directly within a damage area to avoid overestimated reading. Decision on damage assessment are primarily based on the remaining ligament thickness. Getting a reliable reading is thus important.

APPENDIX III

Appendix-III.1

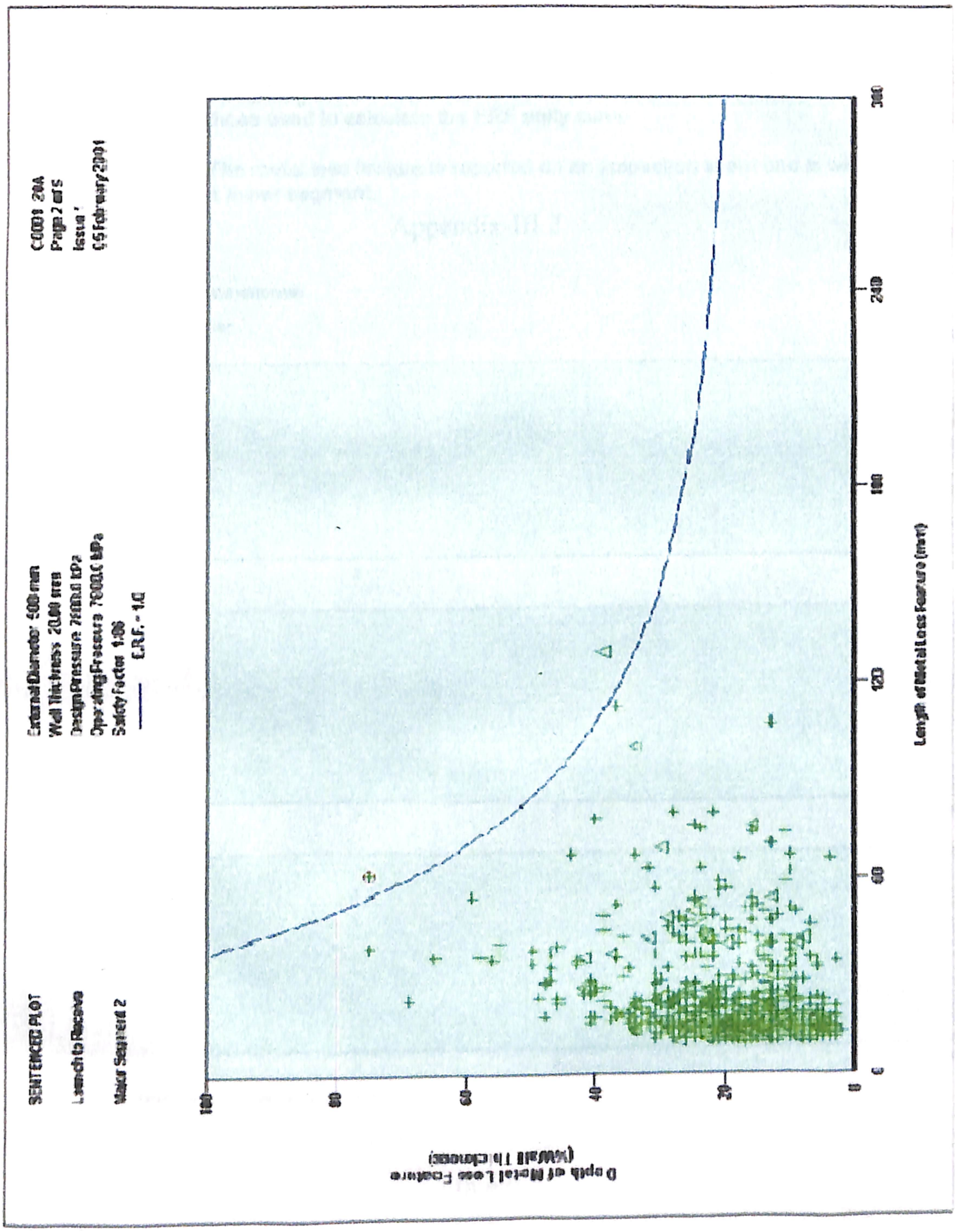


Fig.8.7

+	The metal loss feature is within the major segment. That is the spool containing the metal loss feature has pipeline parameters equal to those used to calculate the ERF unity curve.
⊕	The metal loss feature is reported on an inspection sheet and is within the major segment.
△	The metal loss feature is within a minor segment. That is the spool containing the metal loss feature has pipeline parameters different to those used to calculate the ERF unity curve.
(△)	The metal loss feature is reported on an inspection sheet and is within a minor segment.

Appendix-III.2

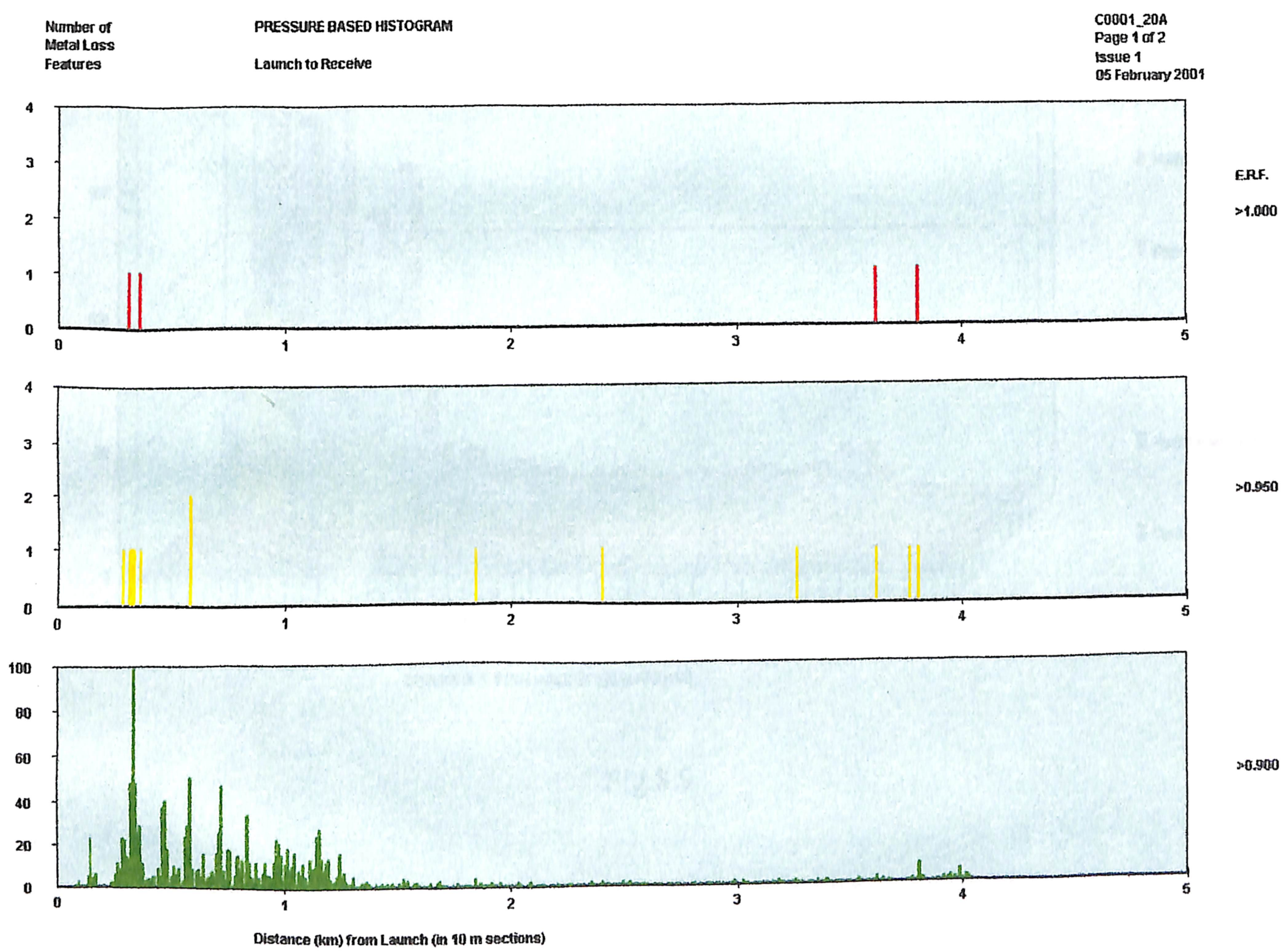


Fig.8.8

Appendix-III.3

DEPTH BASED HISTOGRAM

Launch to Receive

C0001_20A
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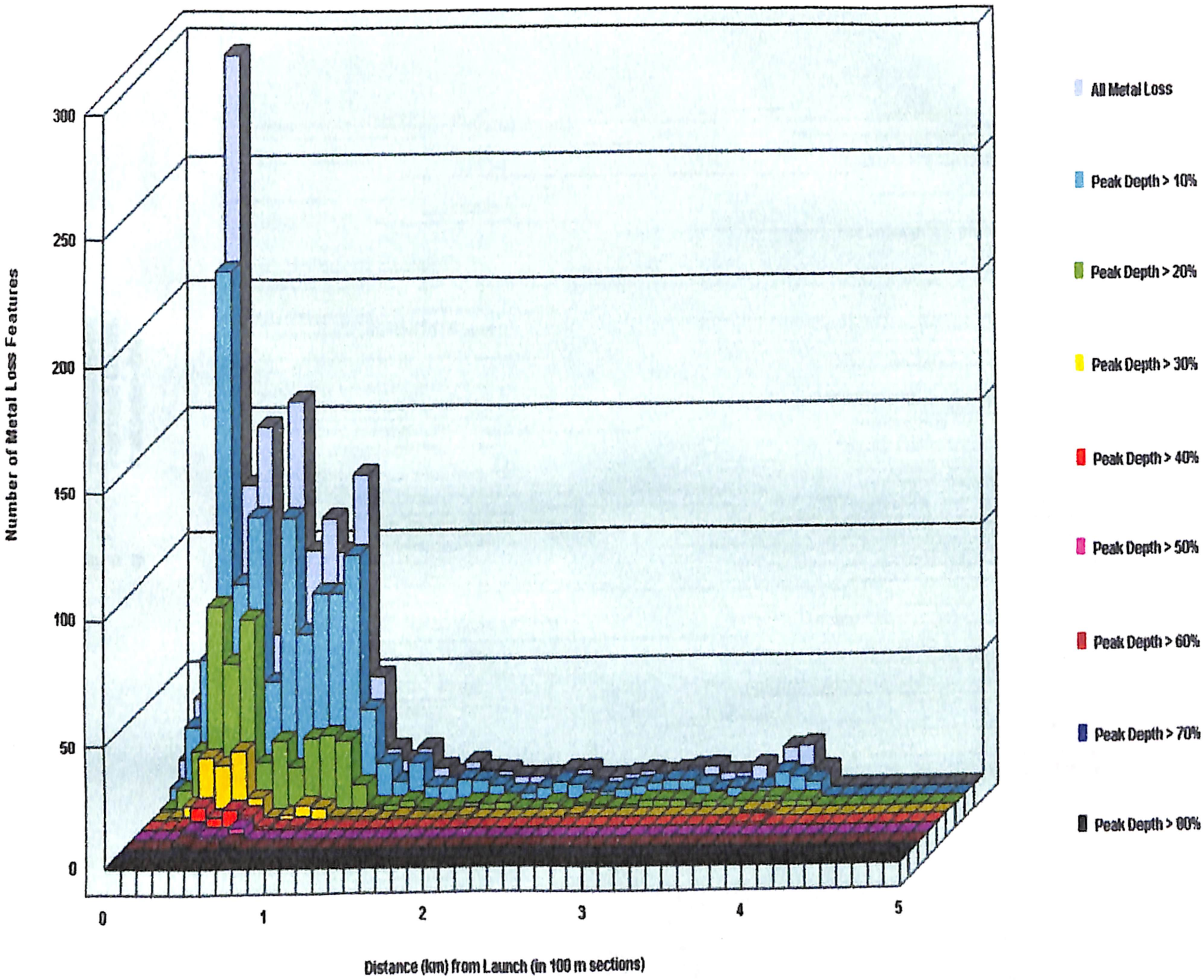

Fig.8.9

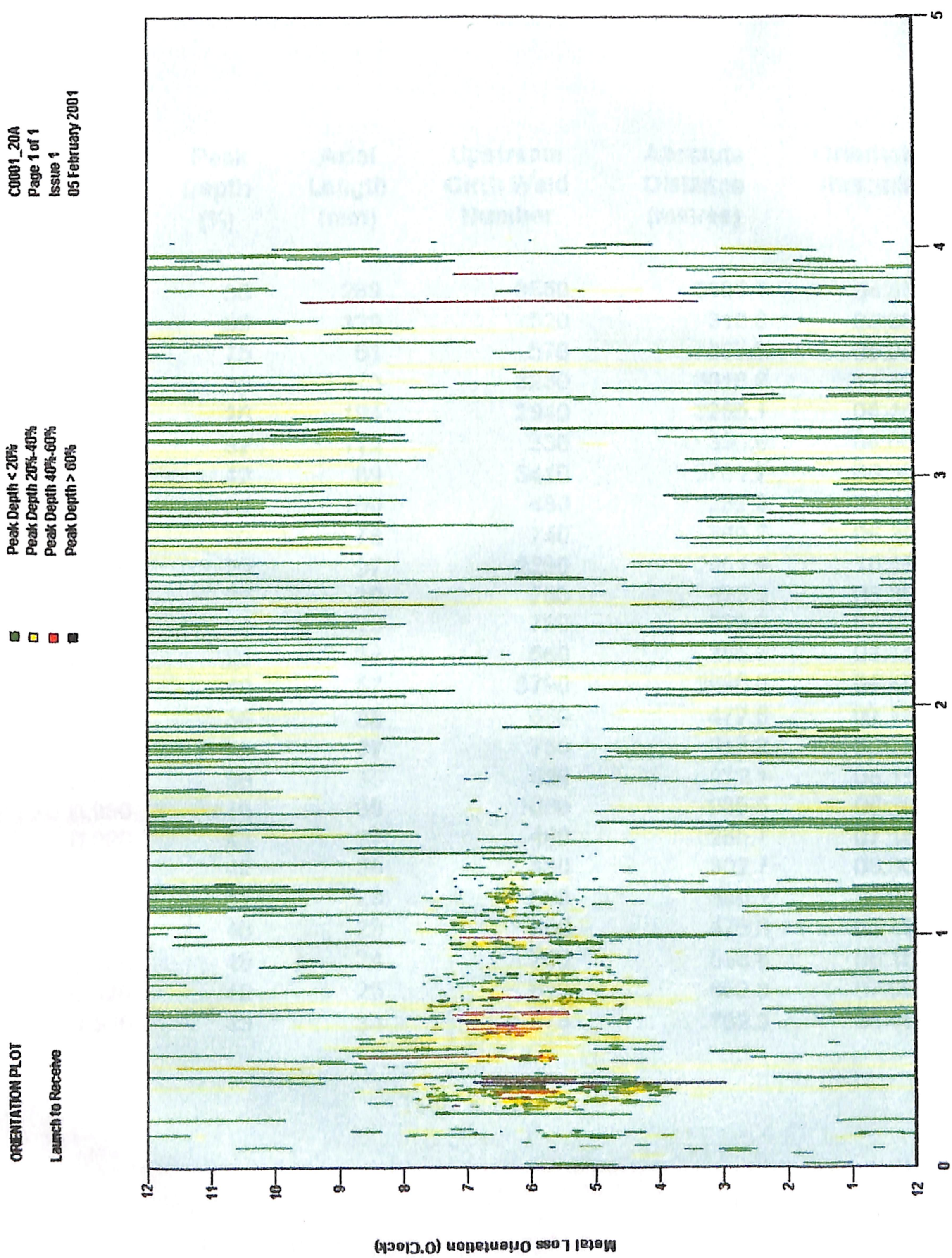

Fig.8.10

Appendix-III.4

Feature Selection Rule	ERF	Peak Depth (%)	Axial Length (mm)	Upstream Girth Weld Number	Absolute Distance (metres)	Orientation (hrs:mins)
1	1.100	38	289	3550	3806.1	04:45
1	1.010	39	129	520	318.8	06:30
1	1.010	75	61	570	367.9	05:00
4	1.010	23	273	3230	3618.9	11:45
5	1.000	26	194	2940	3265.1	08:45
5	0.990	37	112	530	330.6	06:00
5	0.980	42	89	3410	3761.7	06:30
5	0.970	34	100	480	287.3	05:45
5	0.960	40	78	740	583.5	06:30
5	0.960	29	97	2230	2401.9	10:15
5	0.950	75	39	780	623.4	06:30
6	0.920	69	23	790	635.5	07:00
6	0.940	65	36	560	355.7	06:15
7	0.940	42	57	3790	3880.0	06:45
7	0.930	56	35	660	477.5	07:15
7	0.930	55	37	760	611.2	06:30
7	0.930	58	36	820	672.1	06:15
7	0.930	46	39	1080	988.5	06:30
7	0.920	41	27	460	265.7	07:15
7	0.920	42	36	490	302.7	06:30
7	0.920	41	29	580	380.1	06:00
7	0.920	48	28	650	475.3	05:45
7	0.920	49	24	730	568.8	06:15
7	0.920	42	25	810	659.8	07:00
7	0.920	43	34	870	732.9	06:15

Table.8.7

Appendix-III.5

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