Eddy-Current Data Quality Specification for Inspection of Steam Generator Tubes

Volume 1: Bobbin Coil Probe

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Technical Report

Eddy Current Data Quality Specification for Inspection of Steam Generator Tubes

Volume 1: Bobbin Coil Probe

TR-114206-V1

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REPORT SUMMARY

This report provides a specification for a data quality check, which can be performed during the eddy current inspection of steam generator tubes. Implementing the specification is expected to result in improved accuracy in detecting and sizing tube degradation by ensuring that such measurements are only performed on quality data. Additionally, identifying unacceptable data during acquisition is expected to reduce overall inspection time by providing an opportunity to efficiently schedule and perform re-tests on tubes with unacceptable data. Improvements in overall quality of acquired data, by implementing this specification, is expected to contribute to successful development and implementation of an automated data analysis system.

Background

Traditionally, data acquisition operators and data analysts have monitored the quality of eddy current inspection data for steam generator tubes. This data quality checking is typically a visual check that is highly subjective. There are very few industry standards for determining the acceptability of eddy current data. One of the greatest challenges for automated data analysis systems is to provide accurate results without generating an unacceptable number of false calls. Data of marginal quality has resulted in unacceptable results from automated data analysis systems and has lead to significant efforts to develop software algorithms to counteract effects of poor quality data.

Volume 1 of this report addresses the quality of data acquired with a bobbin coil probe. Volume 2 addressees the quality of data acquired with a rotating plus-point probe. Volume 3 provides results of implementing the proposed data quality specification on recently acquired eddy current data from several U.S. plants. Issuance of Volumes 2 and 3 is planned for March 2000.

Objective

To develop an eddy current data quality specification for steam generator tube examinations and to determine the impact of implementing this specification on data acquired from current U.S. inspection systems (such a specification provides utility engineers with criteria that can be specified to ensure minimum acceptance criteria for data quality).

Approach

The project team conducted a systematic investigation on the elements of a data acquisition system and on the role of the data acquisition operator. The team identified essential parameters and proposed methods for evaluating their influence on data quality and repeatability.

Results

The study of data quality issues pertaining to the bobbin coil probe (Volume 1) has led to

- development of twenty data quality parameters
- development of methods to measure the data quality parameters
- development of proposed data quality acceptance criteria
- a recommendation for the design of a Quality Standard

EPRI Perspective

Introducing eddy current data quality requirements into a plant's steam generator program has the potential to improve inspection data quality and repeatability. The expected improvements in the quality of acquired data will assist in optimizing the accuracy of detection and sizing of tube degradation. Additionally, as the industry moves toward greater use of automatic data analysis systems, the quality and repeatability of data becomes a major factor affecting the success of such systems. If improvements in data quality increase the effectiveness and accuracy of automatic data analysis systems—to the point where they become a routine part of an inspection program—then utilities can expect reduced inspection costs.

Implementing data quality requirements into a plant's steam generator program should proceed in a systematic manner. Although methods for measuring each of the various quality parameters are provided, proposed data quality acceptance criteria should be thoroughly evaluated on plant-specific data and modified, depending on utility needs and objectives. To implement the data quality specification on all identified parameters, two actions will be required. The first is to use an in-line standard of similar dimensions to the Quality Standard identified in this report, and the second is to develop software that will automatically perform all data quality parameter checks in real time. These suggested actions should not prevent the utility from implementing selected data quality requirements (based on their current capabilities) to accurately and efficiently perform the measurements.

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Keywords

Steam generators
Eddy current
Quality check
Bobbin coil

ABSTRACT

Current practice, in the American nuclear industry, for performing a quality check on eddy current data from steam generator tube inspections, is essentially a visual check performed by data acquisition operators then by analysts. This verification, supplemented by only one quantitative measurement of sampling rate, is highly subjective.

In this study, each source of non-quality has been associated to a quantifiable parameter. A measurement method and acceptance criteria were then developed for each of these parameters.

The quality check actually requires a specific reference tube. However, this quality standard can be replaced by current calibration standards if a limited (less stringent) quality check is acceptable. The implementation of the quality check does not require modifications of the equipment currently used for the inspections but inspection procedures must be modified to include at least data quality criteria.

LIST OF ACRONYMS

ETSS	Examination technique specification sheet
ID	Inside diameter
LSB	Least significant bit
MSB	Most significant bit
NPP	Nuclear power plant
OD	Outside diameter
PWR	Pressurized water reactor
RMS	Root mean square
SG	Steam generator
S/N	Signal-to-noise ratio
TSP	Tube support plate
TW	Through wall

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1 INTRODUCTION

The purpose of this report is to provide an eddy current data quality specification for steam generator tube testing using bobbin coil probes. This specification should serve as a basis for implementation of data quality requirements as part of a steam generator examination program.

2 BACKGROUND

2.1 Eddy Current Testing Principle

Steam generator tubing inspection is performed, among other methods, using multi-frequency and multi-mode eddy current techniques and bobbin coil probes.

Signals obtained during the acquisition phase of the inspection program are stored as data files and submitted to the analysis phase. Data analysis is then performed by qualified data analysts and/or in some cases by an automated analysis process.

2.2 Inspection Extent

The tubes have different shapes and lengths depending on the design of the steam generator.

The tubes are welded at either end and expanded completely or partially inside a thick plate called a tubesheet. They are held in place by different support structures such as tube support plates along their straight sections or by antivibration bars in the bent sections.

The inspection area corresponds to the complete length of the tube from the end of the tubesheet at one leg to the end of the tubesheet at the other leg. In the case of low row U-bends, the tube can be inspected from both legs with sufficient overlap to ensure total length coverage.

The goal is to detect, characterize and/or size indications attributable to tube wall degradation or to "non-flaw" conditions.

2.3 Bobbin Coil Probe

The bobbin coil probe is made up of two coils connected so that the magnetic fluxes of the induction they create add up one to the other.

The coils are supplied simultaneously, or in multiplexed mode, by alternating currents at various frequencies.

2.4 Calibration Standards

Calibration standards are typically placed in-line between the guide tube assembly and the probe pusher. Signals obtained from calibration standards are used to :

- set up phase angles and to normalize amplitudes,
- establish calibration curves (phase angle vs. percent through wall or amplitude vs. percent through wall),
- establish coefficients for mix channels and to perform mixing,
- verify overall system performance including more specifically certain quality verifications.

A variety of calibration standards are used in the industry. The minimum requirements for a calibration standard, as defined in [1], consist of a section of tubing with drilled flat bottom holes of various depths and diameters:

- A single hole drilled 100% through one tube wall, 0.052 inch diameter for tubing 0.750 inch outside diameter and smaller or 0.067 inch diameter for larger tubing
- A single flat bottom hole, 7/64 (0.109) inch diameter, 60% through wall from the outer surface
- Four flat bottom holes, 3/16 (0.187) inch diameter, 20% through wall from the outer surface, spaced 90 degrees apart in a single plane around the tube circumference
- One flat bottom hole, 0.187 inch diameter, 40% through wall from the outer surface, when conducting examinations in accordance with ASME Code Section XI, 1989 edition, 1990 addenda and later.

3
DATA QUALITY CHECK OVERVIEW

3.1 Basis for Data Quality Check

Data quality is an important parameter influencing the overall performance of a steam generator tube examination system, as it affects both technique performance and analysis performance. Even when implementing qualified techniques, lower quality data will cause a reduction in the actual probability of detection of degradation (ultimately, degradation can be undetected). Even when interpreted by qualified data analysts, low quality data will increase measurement uncertainties.

The obtaining of high quality data becomes extremely important as the industry moves towards automatic data analysis. Some of the checks identified in this report are indispensable in the case of automated analysis. Moreover, a data analyst can sometimes compensate for lower quality data during manual data analysis. As an example, when having to interpret a distorted or noisy signal, the data analyst can perform phase angle determination as "guess angle". Automated analysis is more limited regarding interpretation of distorted or noisy data and requires higher quality data as it is not intended to compensate for the lack of quality.

Data quality has an effect on probability of detection of degradation, sizing uncertainties, axial location uncertainties and orientation uncertainties. Through these uncertainties, data quality also becomes the key factor in data repeatability from one inspection to another.

Data quality checks enable the verification of acquired data in accordance with predefined criteria specified in Examination Technique Specification Sheets.

In the PWR Steam Generator Examination Guidelines [2] the quality check is essentially defined in terms of signal-to-noise ratio. This definition is rather restrictive as it does not take into account quality parameters which are not related to noise. Unquestionably, problems related to noise are the most challenging for the data analyst. Noise can be caused by :

- electronics or some external source, the tube will have to be retested
- tube characteristics ; techniques like frequency mixing can solve the problem.

It is therefore important to differentiate between these two cases.

Other quality parameters are generally easier to identify but they are not always defined in technical specifications and/or procedures.

3.2 Current Data Quality Checking Practices

Today's industry practice shows the existence of data quality checks at different stages of the steam generator tube inspection. A first level of quality checking is performed by the data acquisition operator who is the first person responsible for the quality of the inspection data. The final and overall responsibility for data quality lies with the data analyst who provides a final judgment on data quality issues. Some vendors [8] apply additional data quality checking consisting of the verification of data quality either before recording data during acquisition or, if already acquired, before a transmission of data to analysis. This step is intended to avoid the acquisition of large amounts of low quality data when the quality problem goes undetected during the acquisition phase.

Data quality checking usually consists of the following verifications and measures:

- Visual verification of eddy current signals in order to verify the absence of noise or other undesirable phenomena (insufficient extent tested, saturation, dropout, etc.)
- Signal-to-noise measurements although not used on a regular basis
- Digitization rate measurement in order to verify that a minimum rate is being obtained

As there are no industry standards and acceptance levels for data quality parameters, except digitization rates, the determination of whether the data is acceptable or not is typically subjective and varies from one acquisition operator to another or from one data analyst to another.

Establishing an on-line quality check will, therefore, eliminate this subjectivity.

3.3 On-line Data Quality Check

An on-line data quality check during the data acquisition phase of an inspection should be based on multiple verifications and measurements performed on the signals acquired. The data acquired is considered acceptable if all the test results (verifications or measures) are in conformity with predefined criteria.

The effectiveness of a data quality check is a direct function of the choice of parameters and their thresholds. When too simplified, the quality check has no added value. Conversely, a quality check which is too complex and stringent will be unproductive leading to significant reduction in the data acquisition rate (number of acceptable acquisitions per hour).

By developing software to automatically check data quality, the following benefits could possibly be realized :

- Provide acquisition operators and data analysts with reliable indicators regarding data quality, thus avoiding the subjectivity in acceptance or rejection of the data

- Provide acquisition operators with an on-line "help tool" to detect the origin of problems encountered
- Provide acquisition operators with the possibility of immediately retesting a tube without displacement of the manipulator
- Avoid position errors and/or time loss due to postponed retests accompanied with manipulator displacements
- Reduce number of retests due to a problem not noticed during acquisition (e.g. data from a whole calibration group rejected)
- Enable a real time determination of acquisition quality
- Relieve acquisition operator from the tedious task of performing a visual data quality check,
- Provide data analysts with good quality data recordings and consequently increase detection and characterization capabilities

An automated data quality check [6] will thus enhance the overall system performance but, most of all, the data recorded and stored will be of sufficient quality to be immediately processed by an automated data analysis system.

The full effectiveness of an on-line data quality check can be obtained by performing two types of verifications as regards eddy current signals during each acquisition cycle:

- Verification(s) of the response(s) obtained on known samples
- Verification(s) of the response(s) obtained on the inspected tube itself

First part of verifications necessitates the presence of a tube sample of known characteristics, to perform tests and to compare the eddy current responses with standard values. This report will define minimum requirements for this tube which will be referred to as the "**Quality Standard**". The Quality Standard is considered different from other calibration standards. Section 8 provides discussion on data quality checking requirements and the possibility of using current calibration standards in order to perform quality checks.

3.4 Automated Analysis of Eddy Current Data

A data quality check has to be the first processing algorithm in an automated data analysis software. It must be understood that erroneous analysis results can be obtained from such systems, if the data being analyzed has not been deemed to be of acceptable quality prior to analysis.

4
DEFINITION OF QUALITY PARAMETERS

A systematic analysis of the influence of all the elements of the acquisition system on data quality allows the selection of parameters which are relevant for a data quality check.

Although one given quality concern can be a consequence of one or several problems appearing simultaneously, this report will address each element of the acquisition system separately. The elements discussed are:

- Probe,
- Probe extension cable,
- Eddy current instrument (transmitter / receiver),
- Eddy current instrument (analog-to-digital converter),
- Probe pusher
- Probe manipulator,
- Test procedures and specifications,
- Environment,
- Human factors.

Tables 4.1 to 4.9 provide an analysis of the influence of selected parameters, specifically linked to each of the above listed elements.

In each table :

- the problem which generally occurs on the quality of data is described,
- the actual origin of the problem is investigated,
- a means to identify and/or solve the problem is proposed, and
- a quality parameter to be included in the quality check is identified.

4.1 Bobbin Coil Probe

The probe includes the sensor and links the inspection equipment with the test object; it is then one of the most important elements in the data acquisition system. Therefore, the probe can be at the origin of quality problems as it is submitted to severe constraints such as:

- High temperature

- Humidity
- Shocks at each entry into and/or exit from the tube
- Sliding friction during probe translation

Table 4-1
Quality parameters associated with a probe

Problem	Origin	Problem Identification/Solution	Quality Parameter
Distorted signals, low amplitude signals in absolute mode	Fabrication: wiring error	Post fabrication test	Coils arrangement
Distorted signals, low amplitude signals in differential mode	Fabrication: wiring error	Post fabrication test	Symmetry of differential signals
Temporal relationship between absolute and differential signal	Fabrication: wiring error (test coils wiring inversion)	Post fabrication test	Probe wiring
Offset variation in differential mode	Fabrication: incorrect pairing of test coils	Post fabrication test	Signal imbalance in differential mode
Loss / excess of sensitivity	Design / Fabrication: coil geometry	Post fabrication test	System dynamics
	Operation: poor fill factor / wrong probe	Probe change / Probe choice	
Centering problem: (coil centering)	Fabrication: incorrect assembly	Post fabrication test	Probe centering
Centering problem: bent or broken centering devices	Operation: mechanical fragility	Probe change	Probe centering
Electric failure: coils in short-circuit	Fabrication: wiring error	Post fabrication test	Presence of measurement signals
Electric failure: micro breaks	Operation: intensive mechanical loading	Probe change	Absence of parasitic noise
Externally induced parasitic noise	Design: shielding absent or not adequate	Visual verification of eddy current signals	Absence of parasitic noise
Signal drift	Operation: Stretching of coaxial cables	Stretching procedure for probe shaft	Offset variation

4.2 Probe Extension Cable

The probe extension cable is an additional link generally placed between the probe pusher and the eddy current instrument. Due to its position in the data acquisition system, it can create the problems, identified in Table 4-2.

Table 4-2
Quality parameters associated with a probe extension cable

Problem	Origin	Problem Identification /Solution	Quality Parameter
Distorted signals, low amplitude signals in absolute mode	Fabrication: wiring error	Post fabrication test	Coils arrangement
Distorted signals, low amplitude signals in differential mode	Fabrication: wiring error	Post fabrication test	Symmetry of differential signals
Time relationship between absolute and differential signal	Fabrication: wiring error (coaxial cables wiring inversion)	Post fabrication test	Probe wiring
Noisy signals	Fabrication: coaxial cables quality	Post fabrication test	Signal-to-noise ratio
Parasitic noise (sensitivity to external noise)	Fabrication: coaxial cables quality	Post fabrication test	Absence of parasitic noise
Loss of sensitivity	Fabrication: coaxial cables quality	Post fabrication test	System dynamics
	Operation: extension cable too long	Limit the maximum length	
Offset variation in differential mode	Fabrication: poor coaxial cables pairing	Impedance matching of cables during manufacture	Signal imbalance in differential mode
Parasitic noise (poor contacts, micro breaks)	Operation: connector contacts wear	Connector change	Absence of parasitic noise
Absence of signals	Operation: poor contacts	Connection verification	Presence of measurement signals

4.3 Eddy Current Instrument : Transmitter/Receiver

The eddy current instrument is also an important element in the data acquisition system. The problems linked to the fundamental functions of excitation and reception are listed in Table 4-3.

Table 4-3
Quality parameters associated with the eddy current instrument transmitter/receiver

Problem	Origin	Problem Identification/Solution	Quality Parameter
Noisy signals	Operation: electronic problem	Periodical verification of instrument.	Signal-to-noise ratio
Parasitic noise (sensitivity to EMF[1])	Design: shielding and sensitivity to external noise	Qualification tests	Absence of parasitic noise
Frequency coupling (in simultaneous mode)	Operation: drift in frequency	Visual verification of eddy current signals	Signal-to-noise ratio
Frequency exactness	Operation: drift in frequency	Periodical verification of instrument.	Measurement on reference defects
Poor or too high phase angle difference between known defect signals	Operation: exactness of frequencies	Periodical verification of instrument.	Measurement on reference defects
Too high or too low amplitude of signals	Operation: poor linearity in amplitude	Periodical verification of instrument.	System dynamics
Signal Offset	Operation: poor instrument balancing	Balancing on regular basis	Offset
Signal drift (temperature induced)	Operation: poor temperature resistance behavior	Visual verification of eddy current signals	Offset variation
Signal drift	Operation: electronic problem	Visual verification of eddy current signals	Offset variation
Dropout without information loss	Operation: electronic problem	Visual verification of eddy current signals	Offset variation
Dropout with information loss	Operation: electronic problem	Visual verification of eddy current signals	Offset variation Digitization rate (speed) / Measure of the length of the known event

[1] Electromagnetic field

4.4 Eddy Current Instrument: Analog-to-Digital Converter

The impedance variation signal which is the basic principle of eddy current testing is always an analog signal. It is nowadays almost systematically digitized by the eddy current instrument at stages which mainly depend on the technology of the manufacturer. This essential step of the eddy current signal production can induce the problems listed in Table 4-4

Table 4-4
Quality parameters associated with the eddy current instrument A/D converter

Problem	Origin	Problem Identification/Solution	Quality Parameter
"Jagged" signals	Operation: electronic problem	Visual verification of eddy current signals	Correct digitization
Loss of a channel(s)	Operation: electronic problem	Visual verification of eddy current signals	Presence of measurement signals
Empty data file (no digitization)	Operation: electronic problem	Visual verification of eddy current signals	Presence of measurement signals
Inversion of channels	Operation: electronic problem	Visual verification of eddy current signals	Measurement on reference defects

4.5 Probe Pusher

The probe pusher-puller is an electro-mechanical device adopted worldwide to remotely introduce the probe in a steam generator tube and bring it back. The presence of mechanical and electrical "links" with the eddy current probe is then a potential source of the problems summarized in Table 4-5.

Table 4-5
Quality parameters associated with a probe pusher

Problem	Origin	Problem Identification/Solution	Quality Parameter
Loss of speed in tube / calibration standard / quality standard	Operation: length and positioning of conduit.	Optimization of conduit length.	Digitization rate.
	Operation: wear or poor state of driving wheels	Change wheels regularly	Digitization rate
	Operation: lack of pressure in driving system	Regulate wheel pressure	Digitization rate
Insufficient test extent	Operation: blockage of a tube preventing passage of a probe	Visual verification of eddy current signals	Extent tested
Noisy signals (slip rings)	Operation: track wear	Visual verification of eddy current signals	Signal-to-noise ratio
			Absence of parasitic noise
Parasitic noise (motor)	Operation: poor parasitic noise suppression	Visual verification of eddy current signals	Absence of parasitic noise
Probe speed incorrect	Operation: speed adjustment	Visual verification of displayed digitization rate	Digitization rate / Measure of the length of the known event
	Operation: wear of probe pusher drive wheels		
Variation of the probe speed	Operation: presence of deposits inside the tube	Visual verification of displayed digitization rate	Digitization rate / Measure of the length of the known event
	Operation: wear of probe pusher drive wheels		

4.6 Probe Manipulator

The probe manipulator is linked to the probe pusher by a hose or conduit and is remotely operated to move the guide-tube from one tube inlet to another. Two main problems, listed in Table 4-6 can occur which are strictly related to this element of the data acquisition system.

Table 4-6
Quality parameters associated with a probe manipulator

Problem	Origin	Solution	Quality Parameter
Position error	Operation: wrong tube coordinates	Visual verification by operator or automated verification by software	Comparison of measurements performed on known specific defect(s)
Variation of the axial speed	Operation: conduit length and arrangement	Optimization of the length and arrangement of the conduit	Digitization rate

4.7 Test Procedures and Specifications

Inadequate setup of the eddy current instrument can create problems such as signal saturation or signal quantification errors.

If the injection level and/or the gain are too high, a risk of saturation exists at the input stage of the eddy current instrument and/or A/D converter level. If, on the contrary, the injection and/or the gain are too low, there is a loss in signal definition. A low amplitude signal digitized with an insufficient number of bits can lead to a significant measurement error. In the case of low injection and high gain, there is a risk for degradation of signal-to-noise ratio. Table 4-7 lists these problems and the related quality parameters

Table 4-7
Quality parameters associated with test procedures and specifications

Problem	Origin	Problem Identification/Solution	Quality Parameter
Saturated signals	Operation: eddy current instrument setup error	Setup procedure	Absence of saturation.
Low amplitude signals	Operation: eddy current instrument setup error	Setup procedure	System dynamics
Noisy signals	Operation: eddy current instrument setup error	Setup procedure	Signal-to-noise ratio

4.8 Environment

The general conditions of a steam generator tube inspection are specified in a document where the duties of the plant owner as far as steam generator preparation is concerned are stated. The probe is consequently designed to operate in a precise range of temperatures and humidity.

Table 4-8
Quality parameters associated with environment

Problem	Origin	Problem Identification/Solution	Quality Parameter
Signals drift	Operation: difference in temperature between the SG and ambient	Testing postponed after temperature drop	Offset variation
Parasitic noise (micro breaks)	Operation: too high humidity level inside a tube	Tube drying	Absence of parasitic noise

4.9 Human Factors

Data acquisition is performed by trained and certified personnel, according to precise procedures, thus ensuring a certain level of data quality. Nevertheless, human “imperfections”can be at the origin of the data quality problems which are listed in Table 4-9.

Table 4-9
Quality parameters associated with human factors

Problem	Origin	Problem Identification/Solution	Quality Parameter
Position error	Operation: wrong tube coordinates typed in by operator	Periodical position verification	Comparison of measurements performed on known specific defect(s)
Incomplete extent tested	Operation: errors related to start and/or end of cycle	Visual verification of eddy current signals	Extent tested
Absence of calibration standard	Operation: errors related to start and/or end of calibration group	Verification of data directory	Presence of a calibration standard
Absence of quality standard	Operation: errors related to start and/or end of cycle	Visual verification of eddy current signals	Presence of the quality standard
Identification error (SG number, unit number, leg, etc.)	Operation: wrong information entered by operator	Verification during acquisition process	Verification against external data file
Empty file or no file	Operation: poor or no recording on storage unit	Verification of the presence and correctness of data file	Presence of measurement signals

4.10 Quality Parameter Groupings

The parameters have been grouped into three classes related to the magnitude of their affect on overall data quality and to the possibility of recovering the data. The quality parameter groupings include:

- **parameters drastically affecting the data quality**. No recovery is possible, data cannot be analyzed and the tube must be retested, see Table 4-10.
- **parameters significantly affecting the data quality**. Recovery is possible when the problem occurring is limited. Solutions can be found for a correct data interpretation, e.g. data interpolation in the case of low digitization rate, filtering in the case of poor S/N ratio etc., see Table 4-11.
- **parameters partially affecting the data quality**. Recovery is usually possible applying simple means such as hardware/software null, spike filtering and/or signal amplification, see Table 4-12.

It is obvious that a given problem can lead to several different non-quality issues each of them having a different degree of importance to quality. Therefore, the same quality parameter can figure in more than one table given below. An “error code” is also proposed for ease in categorizing data quality issues.

Table 4-10
Parameters drastically affecting the quality

Quality parameter	Symptom of a possible problem	Primary cause of problem	Recovery	Error code
Extent tested	Insufficient extent tested	Human factor / tube blockage	Not possible	QET
Presence of a calibration standard	No calibration standard entry or no signals	Human factor	Not possible	QCS
Presence of the quality standard	No quality standard signals	Human factor	Not possible	QQS
Correct digitization (absence of loss of bits)	Information incorrect since the status of one or several bits has not changed	A/D converter	Not possible	QLB
Saturation	Saturated signals in tube and/or in calibration standard / quality standard	Eddy current instrument setup and/or balancing	Not possible	QSS
Measurement on reference defects	Known artificial defects out of phase or with improper amplitude	Electronic problem / frequencies / connection	Not possible	QMD
Signal dropout	Sudden drift of signal base line	Electronic problem / connection	Not possible	QDO
Coils arrangement	Distorted signals, Low amplitude signals	Probe / probe extension cable	Not possible	QWA
Identification (SG number, unit number, leg, etc.)		Human factor	Possible, if discovered	QTI
Position verification	Wrong evolution of known flaw signals	Position error	Not possible	QPV

Table 4-11
Parameters significantly affecting the quality

Quality parameter	Symptom of a possible problem	Primary cause of problem	Recovery	Error code
Presence of eddy current signals	One or several channels without any eddy current signals	Eddy current instrument	Possible for certain channel(s)	QPS
Digitization rate	Distorted signals / low resolution	Eddy current instrument (sampling) and probe speed	Possible by interpolation	QDR
Probe speed variation	Poor sizing	Probe pusher / tube conditions / conduit	Possible, by interpolation	QSV
Probe wiring	Inverted lobes	Probe / probe extension cable	Possible	QPW
Symmetry of differential signals	Dissymetric signals, distorted signals	Probe / probe extension cable	Possible	QDS
Signal-to-noise ratio	Low S/N ratio	Eddy current instrument / probe / motor unit	Possible, if not too low	QSN

Table 4-12
Parameters partially affecting the quality

Quality parameter	Symptom of a possible problem	Primary cause of problem	Recovery	Error code
Absence of parasitic noise	Parasitic noise	Probe / connectors / environment / eddy current instrument	Possible, if not too important	QPN
Probe centering	Amplitude variation	Probe	Possible	QPC
Imbalance of probe	Offset variation in differential mode	Probe / probe extension cable	Possible	QPI
Offset	System out of balance	Eddy current instrument balancing	Possible if no saturation	QOS
Offset variation	Signal drift	Eddy current instrument / temperature	Possible, if no saturation	QOV
System dynamics	Poor amplitude of reference defects signals	Eddy current instrument setup / probe	Possible, if no saturation	QSD

5
MEASUREMENT AND VERIFICATION OF QUALITY PARAMETERS

This chapter provides a description of data quality measurement and verification methods. Such methods:

- establish the link between a given quality parameter and an implementation of a measurement or verification
- enable, when possible, the performance of manual measurement and verification, in order to estimate the possible impact of a data quality verification on current US industry practice
- serve as a basis for the development of an automated data quality verification tool

Data quality measurement and verification methods should be implemented such that they do not interfere with data acquisition. Examples given here are taken from data recorded at either US or French plants.

Measurement and verification methods shall in no way modify nor interfere with the data acquired. Examples given here are taken from data recorded at either US or French plants.

5.1 Tube Identification

This is the first data quality verification performed. It is performed using the file header and/or external file information. It is intended to verify the absence of incoherence or inconsistencies in the data file. The following information shall be verified:

Data common to one calibration group:

- Power plant name
- Unit number
- Steam generator number
- Steam generator probe entry leg
- Probe type and serial number
- Calibration standard type and serial number

Data related to each tube:

- Row (line) number
- Column (tube) number

5.2 Presence and Quality of Encoding Signals

As encoding signals are not currently used with bobbin coil probes, it is not necessary to test this parameter.

5.3 Extent Tested

Full Length

This verification is not carried out in the case of a partial length examination of the tube.

Verification is performed using low frequency raw signals as shown in Figure 5-1. It consists of checking for the existence of two transitions (air/tube and tube/air) thus defining zones of interest in the data file. This verification uses the subdivision of the recording, a method described in Appendix A.

This verification is performed with the Quality Standard signals at the end of the data file (acquisition on pull). For an acquisition performed on push, an inversion of the file will be necessary.

After defining the three zones mentioned above, the extent tested is verified using the data from the zone marked "tube". This verification leads to a precise determination of the part of the recording corresponding to the examined area ; only this portion will be considered in the subsequent analysis.

Test is considered satisfactory if both transitions are detected.

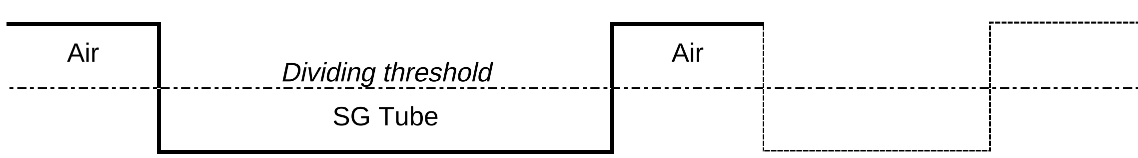

Figure 5-1
Signal amplitude of a full length recording on the lowest frequency in absolute mode

Partial Length

This verification is not carried out in the case of a full length examination of the tube.

Verification is performed using low frequency raw signals as shown in Figure 5-2. It consists in checking for the existence of a single tube/air transition at the end of the inspection area thus defining zones of interest in the data file. This verification uses the subdivision of the recording, a method described in Appendix A.

This verification is performed with the Quality Standard signals at the end of the data file (acquisition on pull). For an acquisition performed on push, an inversion of the file will be necessary.

This verification leads to the definition of zones of interest in the data file, and specifically the part of the recording corresponding to the examined area ; only this portion will be considered in the subsequent analysis.

Test is considered satisfactory if one transition is detected.

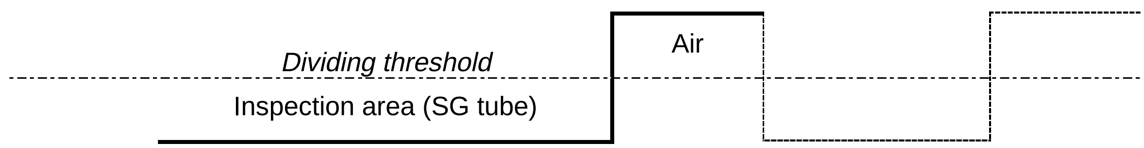

Figure 5-2
Signal amplitude of a partial length recording on the lowest frequency in absolute mode

Landmark detection

This verification consists of the following:

- Measure of the total length of the zone tested
- Automatic detection of support structures

Once the inspection area has been determined, the verification then consists of detecting and counting the number of support structures in the inspection area.

5.4 Presence of a Calibration Standard

It is assumed that current US practice regarding initial and final calibration standard runs remains unchanged and that quality checks, other than those performed on tube data, are carried out on the Quality Standard which will be discussed later.

A calibration group is an arbitrary grouping of tubes in a time interval when essential variables remain unchanged. Current practice shows the presence of one or several calibration standard recordings at the beginning and at the end of each calibration group. As the presence of a calibration standard run is mandatory, verification consists of :

- checking for the presence of a data file encoded as Row 999 Column 999 at the beginning and at the end of the data directory.
- measuring the time elapsed between initial and final calibration standard runs,
- verifying the completeness of the calibration standard run by checking for the existence of two transitions (air/calibration standard and calibration standard/air), thus defining the zones of interest in the data file.

The first two verifications are performed on the calibation group data directory while the third one is performed on both the initial and the final calibration standard run data file using low frequency raw signals, as shown in Figure 5-3. This verification uses the subdivision of the recording, a method described in Appendix A.

The test is considered satisfactory if :

- the calibration group includes at least one valid recording of the calibration standard data file at its beginning and at its end,
- the time elapsed between initial and final calibration standard run is shorter than the acceptance criterion defined in Section 6, and
- transitions in initial and final calibration standard run are detected.

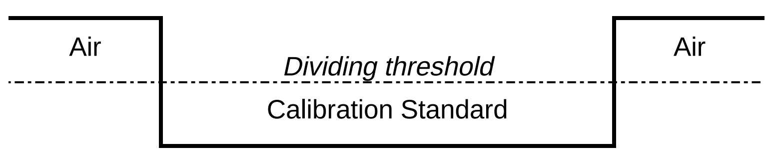

Figure 5-3
Calibration standard signal amplitude on the lowest frequency in absolute mode

The tests involving the initial calibration standard run are performed on the initial data acquired in each calibration group. No tube data acquisition should be allowed until a valid initial calibration standard run is obtained.

The tests involving the final calibration standard run are performed after the closing of each calibration group. The closing is normally not allowed without a final calibration run. The exception is a situation where final calibration standard run is impossible due to equipment malfunctionning (e.g. probe breakdown).

The time elapsed is verified between initial calibration standard run and each subsequent data file. The operator receives a warning when the maximum allowed time is about to be reached, so that he can record a final calibration standard run.

5.5 Presence of the Quality Standard

Verification is performed using low frequency raw signals after defining zones of data file as described earlier under "extent tested" verification and shown in Figure 5-4. It consists of checking for the existence of two transitions (air/Quality Standard and Quality Standard/air), thus defining the zones of interest in the data file. This verification uses the subdivision of the recording, a method described in Appendix A.

The test is considered satisfactory if both transitions are detected. The validity of this test is a prerequisite for other tests performed using the Quality Standard.

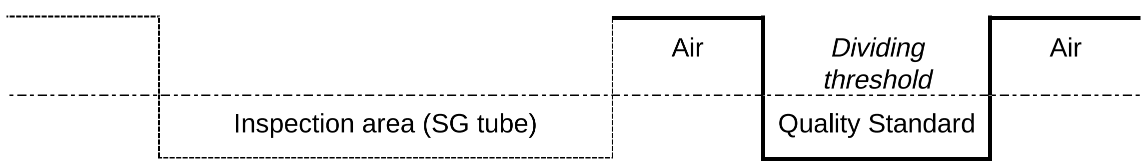

Figure 5-4
Quality Standard signal amplitude on the lowest frequency in absolute mode

5.6 Digitization – Loss of Bits

The loss of bits is characterized by an invariability of 0 or 1 of a single or several digitizing bits. The test consists of verifying that, in the zone defined, the status of all data bits changes at least once, on any given channel.

Verification is performed using raw signals before calibration. It is carried out in the zone where the highest amplitude signals are expected, the most appropriate zone being a transition between the tube and the air. The test is first performed on one channel until the status of each digitization bit is found to have changed at least once. If this is not the case, another channel is scanned, and so on until the change is found.

The test is considered acceptable if the status of each individual digitization bit changes at least once. The test is considered acceptable for the complete recording since the loss of bits is not a random phenomenon which can appear and disappear but rather a steady phenomenon created by electronic malfunctioning.

5.7 Saturation

Verification is performed on all measurement channels using raw signals, before phase angle adjustment and voltage normalization (before calibration). It is carried out in areas susceptible to signal saturation. These areas include:

- entire calibration standard tube,
- entire quality standard tube,
- expansion transition(s),
- low row U-bends (if tested).

Analog saturation is reached when the parameter being measured reaches its extreme value (maximum or minimum). Digital saturation is attained when the parameter being measured meets any one of the limit values of the digitization range expressed in points. Table 5-1 shows those values.

Table 5-1
Maximum and minimum point values for 12 and 16 bits digitization

A/D converter	12 bits	16 bits
Maximum point value	+ 2047	+ 32767
Minimum point value	- 2048	- 32768

The result is acceptable if there is no measurement reaching either the maximum or the minimum digitization value. In other words, the eddy current signal recorded using a given dynamic range of the analog-to-digital converter is not distorted after digitization.

Figure 5-5 shows the distortion of a Lissajous signal caused by the saturation of two Y(t) components of the signal.

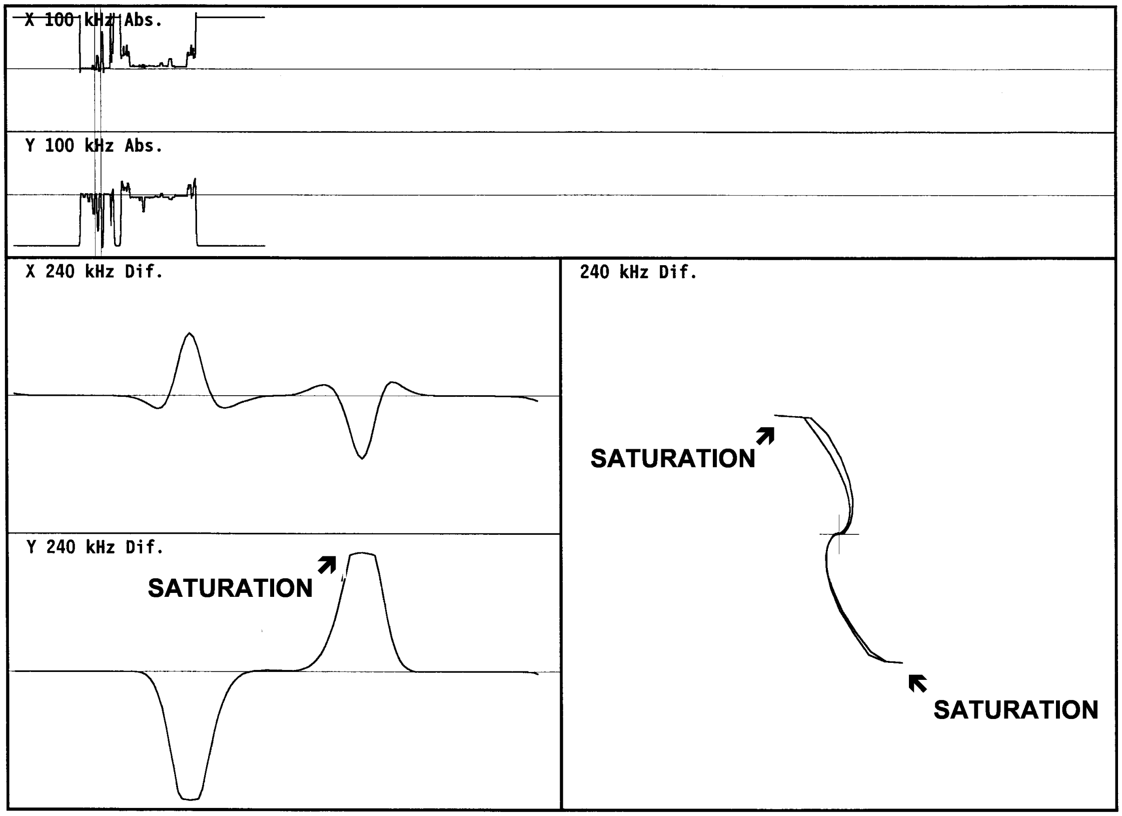

Figure 5-5
Signal Saturation

5.8 Measurement on Reference Defects

A reference defect, as defined here, corresponds to an artificial defect on the Quality Standard with known normal eddy current response. Responses from non through-wall defects are measured at all inspection frequencies and compared to predefined known values.

Difference(s) in amplitude and/or in phase can be caused by two different potential problems. One potential problem resulting from wrong drive voltage and/or gain leading to poor system dynamics, can usually be recovered from. Recovery from the problems arising when wrong frequencies are applied, or in the case of the inversion of measurement channels due to an electronic problem, or simply due to the choice of frequencies is more difficult.

This test consists in an automatic detection of appropriate ID and OD defects, followed by a measurement of the phase of each signal. The value of interest is the phase shift between ID and OD defect signals for each frequency ; this phase shift increases with increasing frequency. Any other behavior of phase shift means that a wrong frequency was applied.

Assuming that the injected frequencies are f_1, f_2,…,f_n where $f_1 > f_2 > \ldots > f_n$, the phase shifts between ID and OD defect signals $\Delta\varphi_1$, $\Delta\varphi_2$,…, $\Delta\varphi_n$ have to be:

$$\Delta\varphi_1 > \Delta\varphi_2 > \ldots > \Delta\varphi_n$$

5.9 Presence of Eddy Current Signals

The verification of the presence of eddy current signals is performed at all inspection frequencies, using raw signals before calibration. It is carried out in the zone corresponding to the Quality Standard.

The verification consists of measuring the phase difference $\Delta\varphi = \varphi_A - \varphi_B$ between the signals from two defects A and B on the quality standard (e.g. one ID defect and one OD defect). Phase angles φ_A and φ_B are measured and the phase difference is calculated for all frequencies. The phase difference should be different from zero at all frequencies, as shown on Figure 5-6.

The absence of one or more channels causes a null phase difference to be found for the observed frequency.

The test is considered acceptable if a measured phase difference $\Delta\varphi$ is achieved at all frequencies.

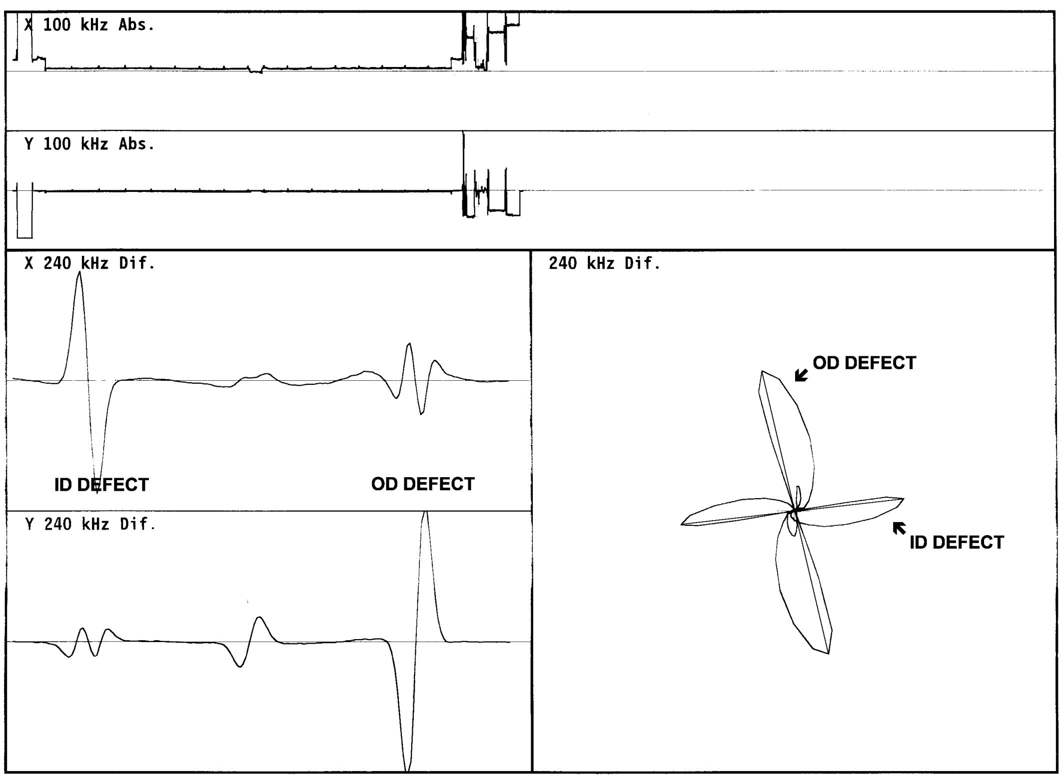

Figure 5-6
Phase difference between the signals from ID and OD reference defects

5.10 Digitization Rate

Digitization rate(*DR*) is expressed as a quotient of the eddy current instrument sample rate (*SR*) and the probe speed (*PS*). It is one of the essential variables of the inspection, defining the resolution of the technique applied and influencing both the probability of detection and measurement uncertainties.

$$DR = \frac{SR}{PS}$$

where:

SR [samples/second] = sample rate,

PS [inch/second] = probe speed,

DR [samples/inch] = digitization rate.

Assuming a constant sample rate of the eddy current instrument, verification of the digitization rate represents in fact a verification of probe velocity.

Nominal digitization rate is an important parameter when evaluating particular technical specifications. In addition to the nominal digitization rate which is verified when ETSS is evaluated, the verification has to be performed on the actual digitization rate obtained during each acquisition cycle.

The measurement is carried out on the inspection base frequency signals in differential mode. The number of digitization points separating the middle of two signals from Quality Standard defects, separated by a known distance, is measured and then compared to the minimum digitization rate.

$$DR = \frac{n}{d}$$

where:

n = number of digitization points measured,

d [inch] = distance between the middle of any two signals of known distance, as shown on Figure 5-7.

DR [samples/inch] = digitization rate.

The test is considered acceptable if the digitization rate in the quality standard is higher than the threshold value determined in Section 6.

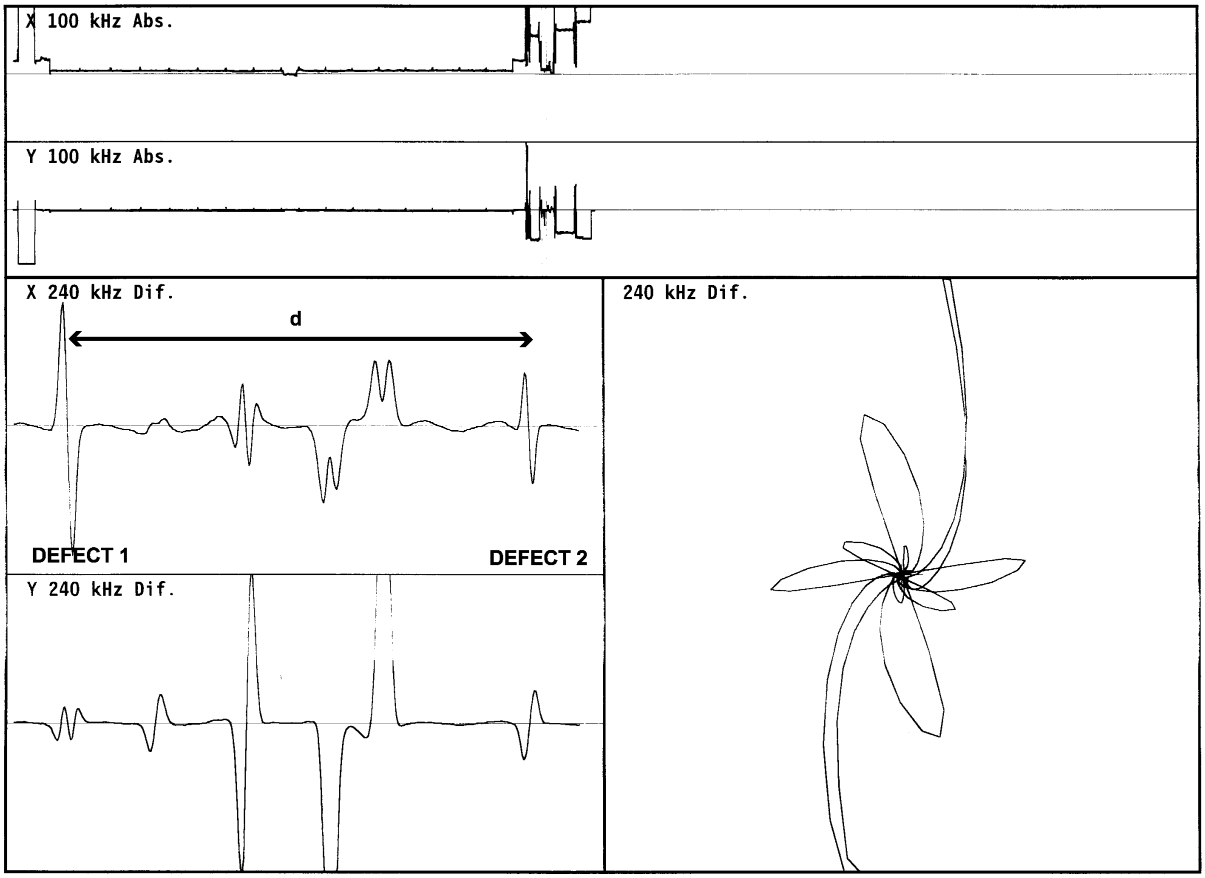

Figure 5-7
Digitization rate measurement

5.11 Probe Speed Variation

This test can be realized only in the presence of successive geometrical events in the inspected zone with known distances between them, assuming detection capability.

The measurement is carried out in the inspection area on the lowest frequency in absolute mode. It consists of a comparison between the calculated distance between two successive geometric events (such as support plates or tube expansion transition areas) and their theoretical distance.

In order to do this, the number of digitization points separating the middle of the two signals corresponding to two successive geometric events is measured and compared to the theoretical number of points.

$$\delta S = \frac{100 \times (n - p)}{p}$$

where:

n [points] = number of digitization points measured,

p [points] = theoretical number of digitization points;

$$p = DR_t \times d$$

DRt [points/inch] = theoretical digitization rate,

d [inch] = distance between the middle of the two defects on the quality standard

δS (%) = speed variation.

The test is considered acceptable if the variation in probe speed measured is less than or equal to the threshold value determined in Section 6.

Figure 5-8 shows one of the several measurements that are performed on each tube.

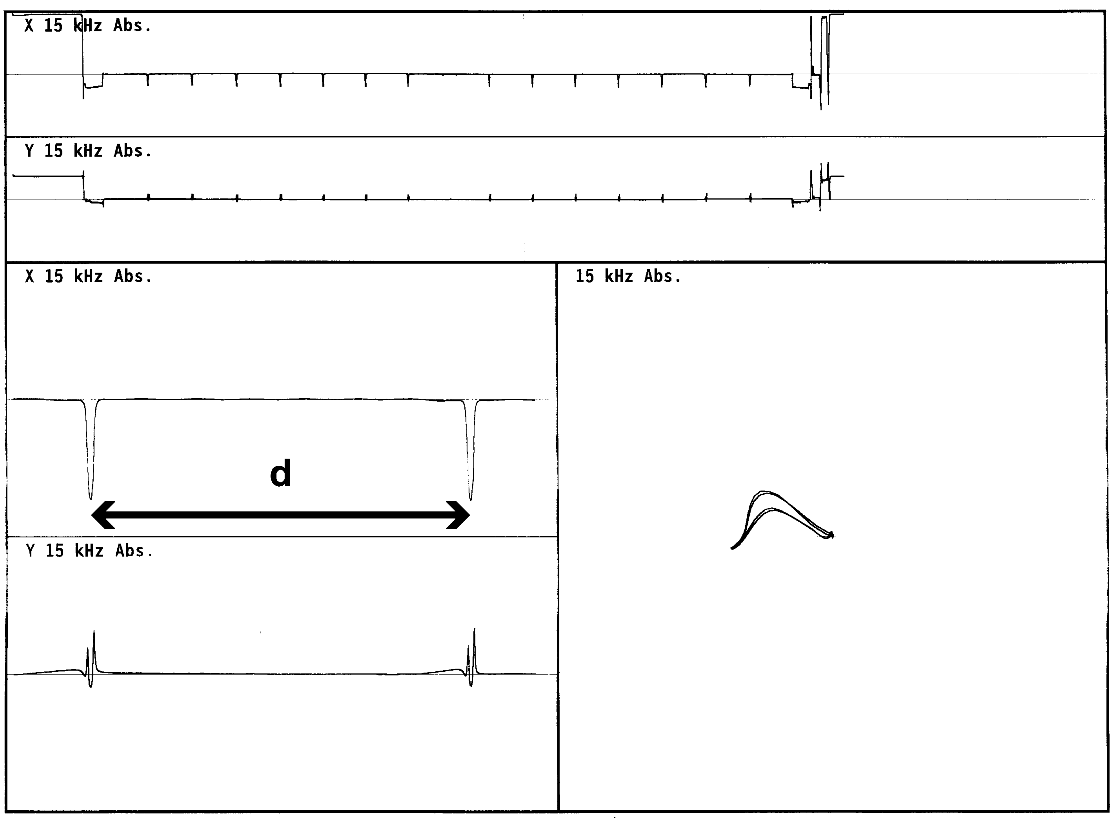

Figure 5-8
Probe speed variation measurement

5.12 Probe Wiring

The probe wiring measurement is carried out on the inspection base frequency in both the differential mode and the absolute mode.

The measurement area corresponds to the reference defect used for amplitude normalization of differential channels.

The distance between the measurement point corresponding to the maximum of the signal lobe in absolute mode and the point corresponding to the middle of the same signal in differential mode is measured. The distance measured is positive if the maximum of the signal lobe in absolute mode is situated in time before the middle of the same signal in differential mode, as shown in.Figure 5-9

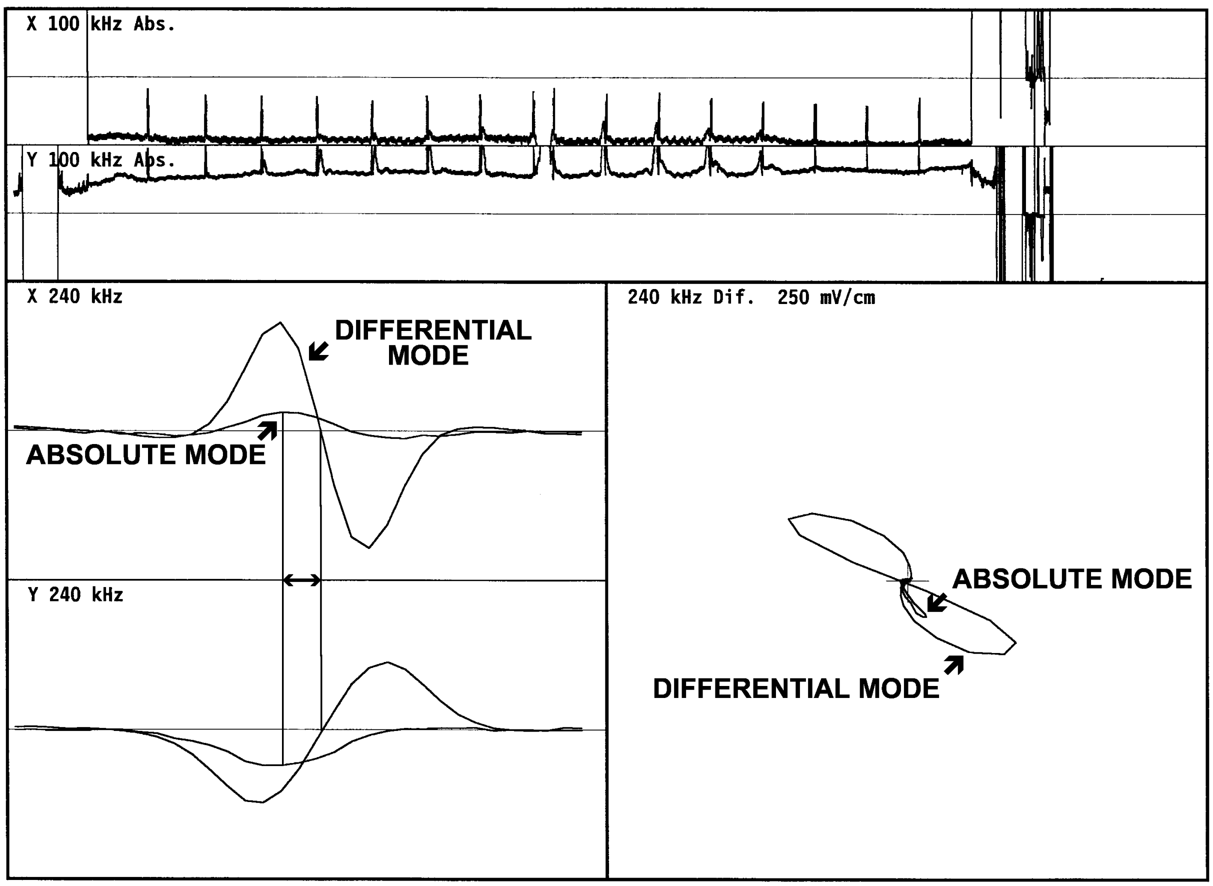

Figure 5-9
Probe wiring verification

5.13 Probe Flux and Coil Arrangement

The measurement for probe flux and coil arrangement is carried out on all inspection frequencies in the absolute mode.

The measurement area corresponds to the reference defect used for amplitude normalization of differential channels.

The secondary lobe amplitude (A_s) and the main lobe amplitude (A_m) of the reference defect signal are measured, see Figure 6-17.

The R_s ratio between the main lobe amplitude and the total signal amplitude (whole signal = main lobe + secondary lobe) is calculated.

$$Rs = \frac{100 \times Am}{Am + As}$$

where:

A_m (volts) = base-to-peak amplitude of main lobe,

A_s (volts) = base-to-peak amplitude of secondary lobe,

R_s (%) = amplitude ratio of lobes.

A perfect absolute signal (see Figure 6-16) has no secondary lobe and the ratio is 100%.

The test is considered acceptable if the ratio between the main lobe amplitude and the total signal amplitude calculated on all frequencies in the absolute mode is greater than or equal to the threshold value determined in Section 6.

5.14 Symmetry of a Differential Signal

The measurement for symmetry of a differential signal is carried out on all inspection frequencies in the differential mode. The measurement area corresponds to the reference defect used for amplitude normalization of differential channels.

Dissymmetry (D_s) of the signal in the differential mode is defined as the difference between the amplitudes of the two reference defect signal lobes.

The base-to-peak amplitudes (A_1) and (A_2) of the two reference defect signal lobes are measured and the difference between them is calculated, as shown on Figure 5-10. This difference is expressed as a percentage in relation to the average of the two lobes.

$$Ds = \frac{200 \times (A1 - A2)}{(A1 + A2)}$$

where:

A_1 (volts) = base-to-peak amplitude of first lobe,

A_2 (volts) = base-to-peak amplitude of second lobe,

D_s (%) = signal dissymmetry.

Perfect symmetry is obtained when the two lobes have equal amplitudes, therefore a dissymmetry value of zero.

The test is cosidered acceptable if signal dissymmetry on each frequency in differential mode is less than or equal to the threshold value determined in Section 6.

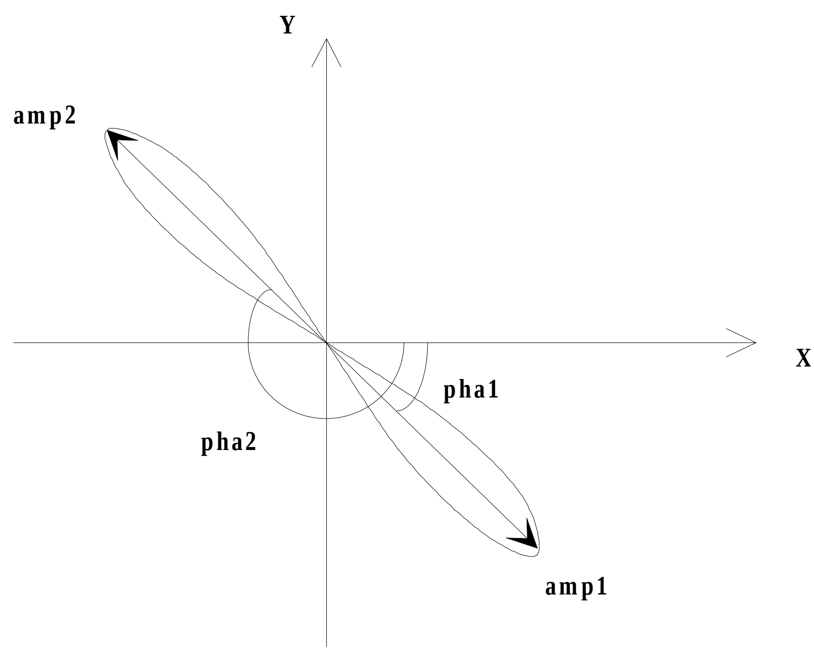

Figure 5-10
Measurement of the signal lobes from the reference defect

5.15 Probe Centering System

The measurement for probe centering is carried out on the base frequency in the differential mode.

The measurement area corresponds to four artificial defects each separated by 90°, in four equally distant axial positions of a calibration standard.

The peak-to-peak amplitudes of the four signals corresponding to the four successive defects are measured.

The measurement dispersion (D_i) is calculated from the average amplitude of the four signals (*M)* and from the maximum deviation from the average (D_{vmax}). Measurement dispersion is expressed as a percentage.

$$Di = 100 \times \frac{|D_{v\max}|}{M}$$

where:

M (volts) = average amplitude of four signals,

D_v = deviation from the average,

D_i (%) = measurement dispersion.

An ideal centering system is characterized by a very low measurement dispersion.

The test is considered acceptable if the measurement dispersion of the amplitudes calculated on the reference frequency in differential mode is less than or equal to the threshold value determined in Section 6.

5.16 Imbalance of Probe

The measurement of probe imbalance is carried out on all inspection frequencies in differential mode after calibration.

The measurement area, (*std*), corresponds to a sound area of the calibration standard or the Quality Standard.

The measurement area, (*air*),corresponds to an area of air situated either in front of the inspection area (SG tube) or between the inspection area and the standard, see Figure 5-11. The width (*n)* of a measurement area shall be approximately 30 points so that slight signal variations are not taken into account.

Probe imbalance (or coil dissymmetry) is defined as the distance measured in volts between the balancing point of the probe positioned in the air and the balancing point of the probe positioned in a sound area of the calibration standard.

The probe imbalance is calculated using the vectorial difference between the moduli of the two balancing points.

X and Y being the coordinates of the point in the impedace plane display,

$$I_P = \sqrt{(X_{air} - X_{std})^2 + (Y_{air} - Y_{std})^2}$$

where:

X_{air} (volts) = average of *n* measurement points for X in the air,

Y_{air} (volts) = average of *n* measurement points for Y in the air,

X_{std} (volts) = average of *n* measurement points for X in the standard,

Y_{std} (volts) = average of *n* measurement points for Y in the standard,

Ip (volts) = probe imbalance.

A perfect probe with a perfectly well balanced extension cable produces a very low imbalance value in differential mode.

The test is considered acceptable if the probe imbalance, calculated for each frequency in differential mode, is less than or equal to the threshold value determined in Section 6.

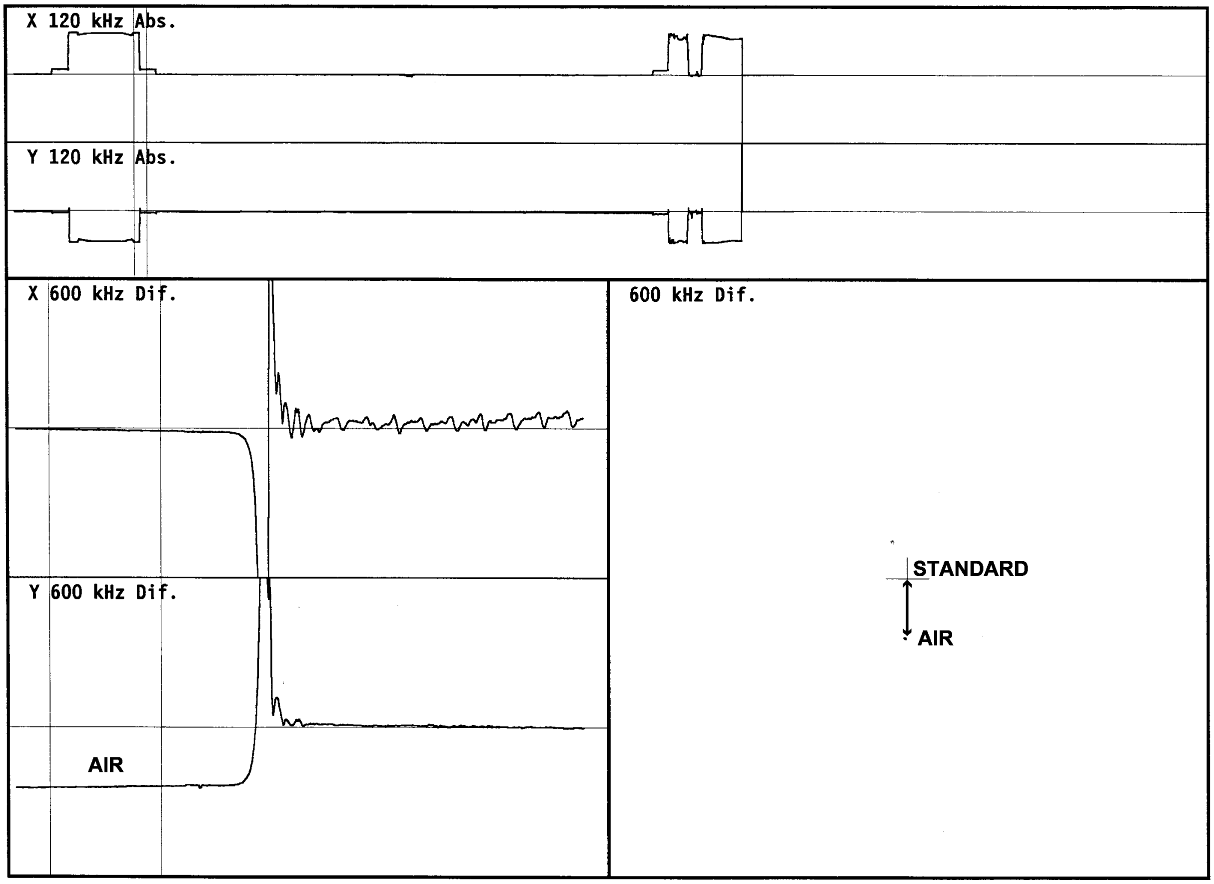

Figure 5-11
Imbalance of probe : measurement zones

5.17 Offset

The verification of offset is performed for all frequencies after calibration, in both the absolute and differential mode. It is carried out twice in a sound zone close to each end of the Quality Standard, (*a* and *b*). One verification is enough to measure the absolute value of the offset, the second one permits the detection of the possible presence of offset variation appearing as a slow variation of signal baseline (see next subsection).

A zone of *n* data points is defined and the average value in that zone is taken as a balance point. This allows the suppression of the influence of signal variations due to electronic noise.

Offset is defined as the distance between a signal balance point and electric "null" with the probe situated in a sound zone of the Quality Standard, as shown in Figure 5-12 and Figure 5-13. This distance is expressed in volts.

Offset O_S being the modulus of signal balance point is calculated for zone *a* and zone *b* of the Quality Standard as:

$$O_{Sa} = \sqrt{X_a^2 + Y_a^2} \qquad O_{Sb} = \sqrt{X_b^2 + Y_b^2}$$

where:

X_a = average of *n* measurement points for X in zone *a*,

Y_a = average of *n* measurement points for Y in zone *a*,

X_b = average of *n* measurement points for X in zone *b*,

Y_b = average of *n* measurement points for Y in zone *b*,

X and Y being the coordinates of the point in the impedace plane display,

O_{Sa} (volts) = offset in zone *a*,

O_{Sb} (volts) = offset in zone *b*.

Test results are pronounced acceptable if both O_{Sa} and O_{Sb} measured on each frequency are lower than a threshold value determined in Section 6.

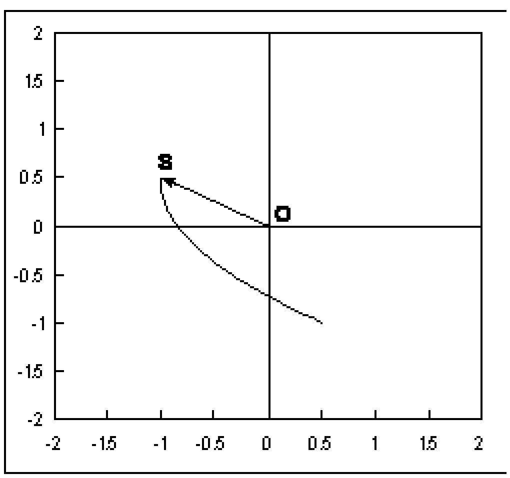

Figure 5-12
Offset in absolute mode

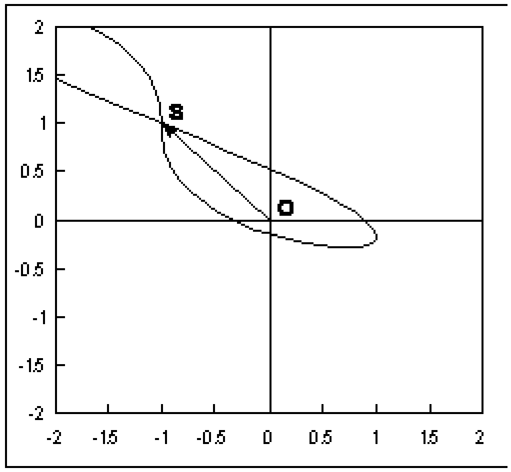

Figure 5-13
Offset in differential mode

5.18 Offset Variation

The drift of the measurement signal is slow deviation of the base line of the signal.

Verification of offset variation cannot be performed in the examination area (SG tube) as it is not possible to make a difference between a drift due to an electronic problem and a drift due to the characteristics of the examined tube. Verification is therefore performed on the Quality Standard which is by design, fabricated from a section of tube showing no variation of physical properties.

The verification of offset variation is carried out on all frequencies after calibration. Measurement is carried out on each extremity (*a* and *b*)of the Quality Standard corresponding to sound areas. The length of each measurement "zone" is approximately 30 points to obtain a fairly constant signal.

The value of the drift, measured in volts, is the distance between the two balancing points of the probe positioned in zone *a* and in zone *b* of the Quality Standard, as shown on Figure 5-14.

The offset variation D_s is calculated using the value of the vectorial difference between the moduli of the two balancing points.

$$D_S = \sqrt{(X_a - X_b)^2 + (Y_a - Y_b)^2}$$

where:

X and Y being the coordinates of the point in the impedace plane display,

X_a = average of *n* measurement points for X in zone *a*,

Y_a = average of *n* measurement points for Y in zone *a*,

X_b = average of *n* measurement points for X in zone *b*,

Y_b = average of *n* measurement points for Y in zone *b*,

Ds (volts) = offset variation.

Test results are pronounced acceptable if offset variation for each frequency is lower than a threshold value determined in Section 6.

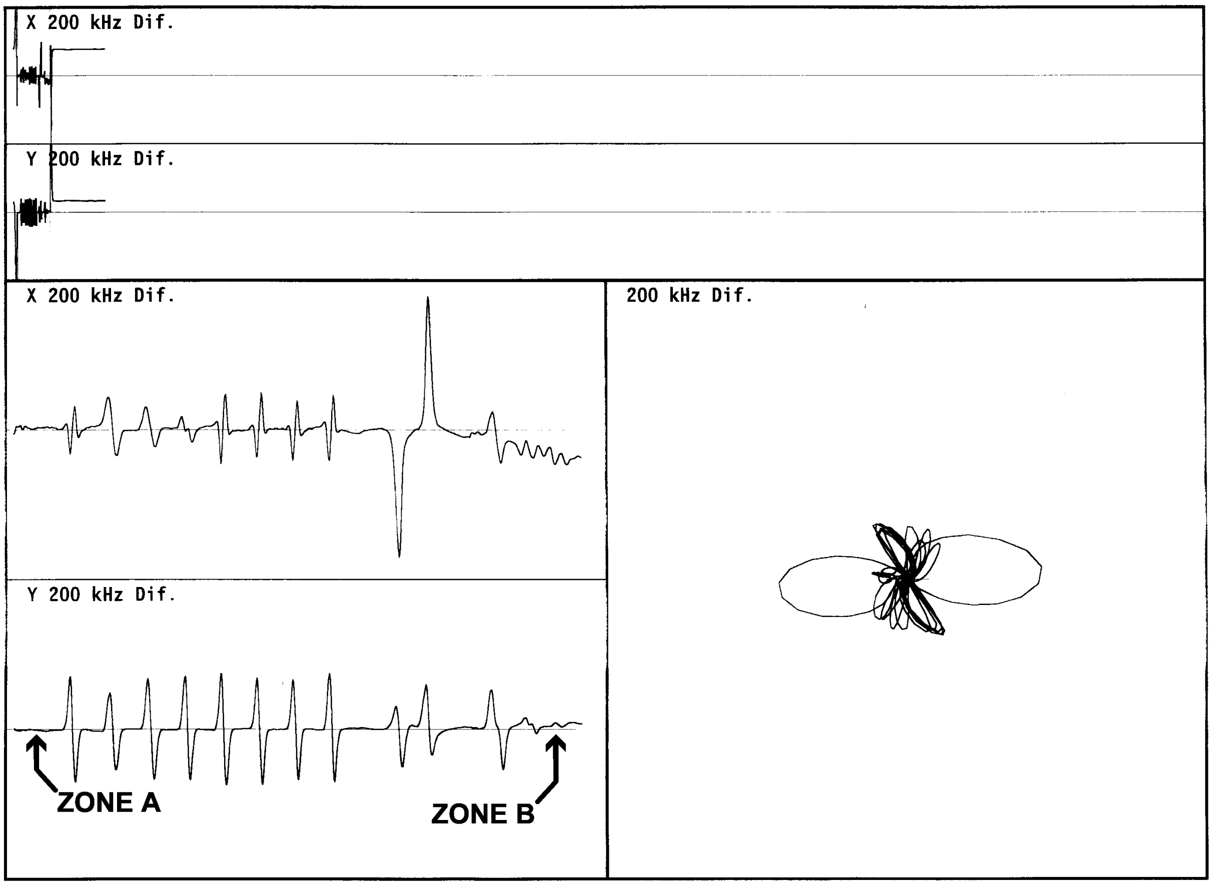

Figure 5-14
Offset variation : measurement zones

5.19 System Dynamics

Verification of system dynamics is performed at all examination frequencies, taking as reference the defect used for amplitude normalization.

The test consists of measuring the amplitude of the reference defect before amplitude normalization and comparing the obtained value with the value of normalized amplitude. Gain correction (C_G) is defined as the difference between a measured value (A_m) and a normalized value (A_t) and it is expressed either as relative difference in percentage or in decibels.

$$C_G = 100 \times \frac{A_m - A_t}{A_t} [\%] \qquad C_G = 20 \log \frac{A_m}{A_t} [dB]$$

Test results are considered acceptable if the calculated gain correction for each frequency is less than or equal to a threshold value determined in Section 6.

5.20 Signal Dropout

Signal dropout, as defined here, corresponds to a sudden change of the signal base line usually due to an electronic problem. The baseline does not move back to the initial position, after the dropout signal. This phenomenon itself does not influence manual data analysis capabilities but it represents an obstacle towards automatic analysis. Furthermore, this event can be associated with partial loss of information, where the dropout is merely a manifestation of an information loss, not the cause.

The signal dropout verification is performed for all frequencies in differential mode after calibration. The entire data file is checked against signal dropout in the following way :

Three adjacent measurement zones (Z_1), (Z_2) and (Z_3) of the same width (*n)* (not less than 300 data points) are defined. The first measurement zone (Z_1) is located at the beginning of the inspected zone, (SG tube) ; these zones are clearly shown in Figure 5-15.

Signal dropout value (*Do*) corresponding to a sudden change of base line is defined as the absolute value of the vectorial difference between "balance points" moduli (M_1) and (M_3) of two measurement zones and it is expressed in volts. In order to examine the entire data file, corresponding to the inspected extent, the process is repeated incrementing zone positions by zone width. Signal dropout is calculated for each successive pair of zones of the examined SG tube as:

$$D_O = \sqrt{(X_1 - X_3)^2 + (Y_1 - Y_3)^2}$$

where:

X and Y are the coordinates of the point in the impedance plane display,

X_1 = average of *n* measurement points for X in the first zone ,

Y_1 = average of n measurement points for Y in the first zone,

X_3 = average of n measurement points for X in the third zone,

Y_3 = average of n measurement points for Y in the third zone,

Do (volts) = signal dropout.

An ideal measurement system does not exhibit signal dropout.

The test result is considered acceptable if the signal drift measured for each frequency in differential mode is less than the threshold value determined in Section 6.

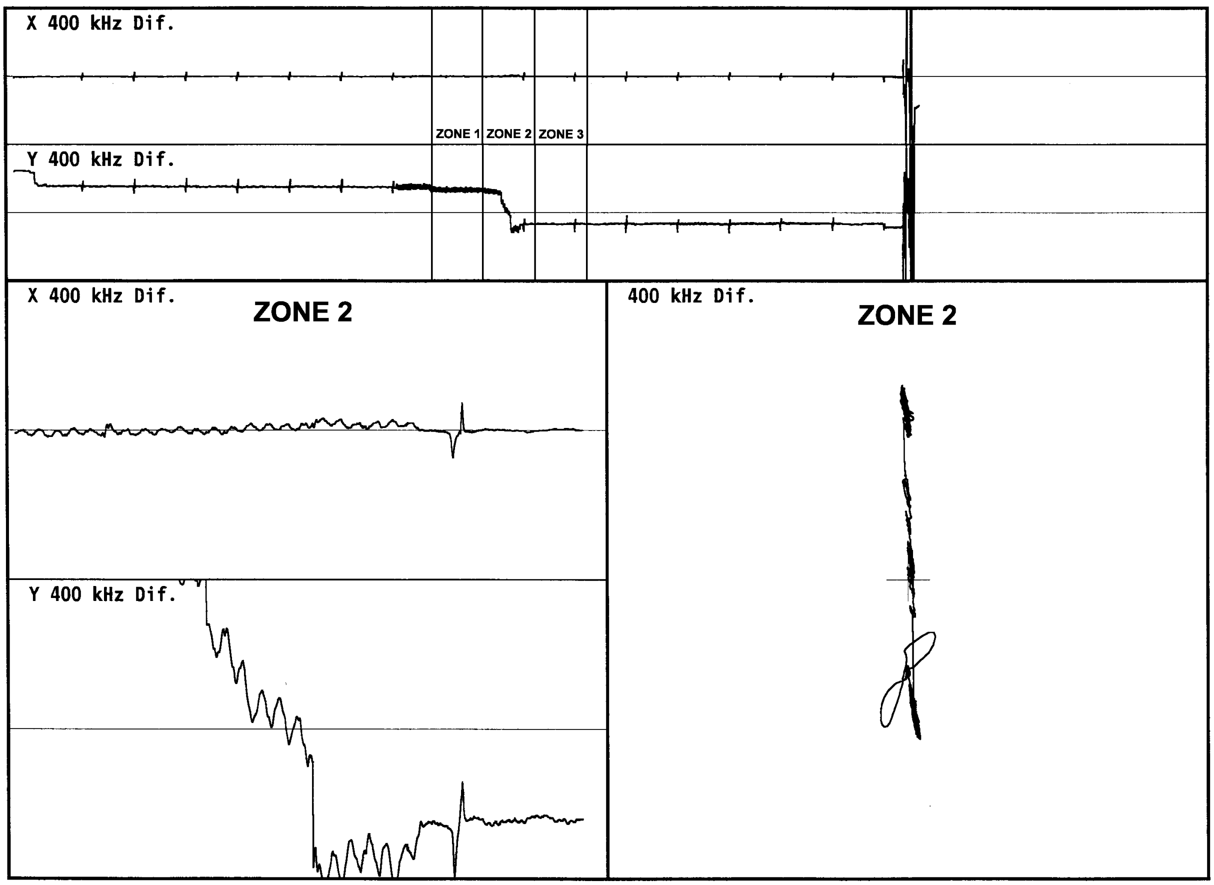

Figure 5-15
Signal dropout : measurement zones

5.21 Signal-to-Noise Ratio

Noise can be classified into three categories:

- Noise of electronic origin. This type of noise is created by the eddy current instrument and associated equipment ; the noise is generated during all phases of signal transmission and/or processing (amplification, demodulation, digitization, etc.). Noise due to probe electrical coil shorts, instrument or cable failure and due to electrical interference from other systems can also be included in this group.
- Noise of mechanical origin. This type of noise is introduced by the movement of coils through the tubing. Noise due to probe wear is an example of this type of noise.
- Noise introduced by the inspected object. This type of noise is introduced by interfering signals related to tubing and/or structure, tube internal surface conditions, electrical and/or magnetic property variations, tube geometric variations, and/or structure signals.

Transposing "noise" defined as above into quality verification implementation, two different kinds of potential interfering conditions can be defined as follows :

- Electronic noise – signals of high frequency with relatively small amplitudes superimposed on the totality or on a part of the data file, usually having long duration (see Figure 5-16)
- Parasitic noise – although all kinds of noise represent a parasitic phenomenon, the term parasitic noise in this document refers to high amplitude signals of usually short duration having high derivation or drift angle, called spikes (see Figure 5-17)

Each type of noise defined above necessitates a measurement and determination of acceptance.

Electronic Noise

The measurement of electronic noise is performed in a sound part of the Quality Standard. The noise amplitude is measured on all frequencies using calibrated signals.

Peak-to-peak amplitude in a narrow zone of 30 data points is measured without any filtering and this amplitude is considered as "noise". The method used for "noise" amplitude measurement is described in Appendix A.

The response of the reference defect used for amplitude normalization is considered as the "signal" value. The method used for "signal" amplitude measurement is described in Appendix A.

Signal-to-noise ratio *S/N* is defined as:

$$S/N = 20\log\frac{A_S}{A_N}$$

where:

A_S (volts) = signal amplitude,

A_N (volts) = noise amplitude,

S/N (dB) = signal to noise ratio.

Test results are considered acceptable if the signal-to-noise ratio for all frequencies is greater than or equal to the threshold value determined in Section 6.

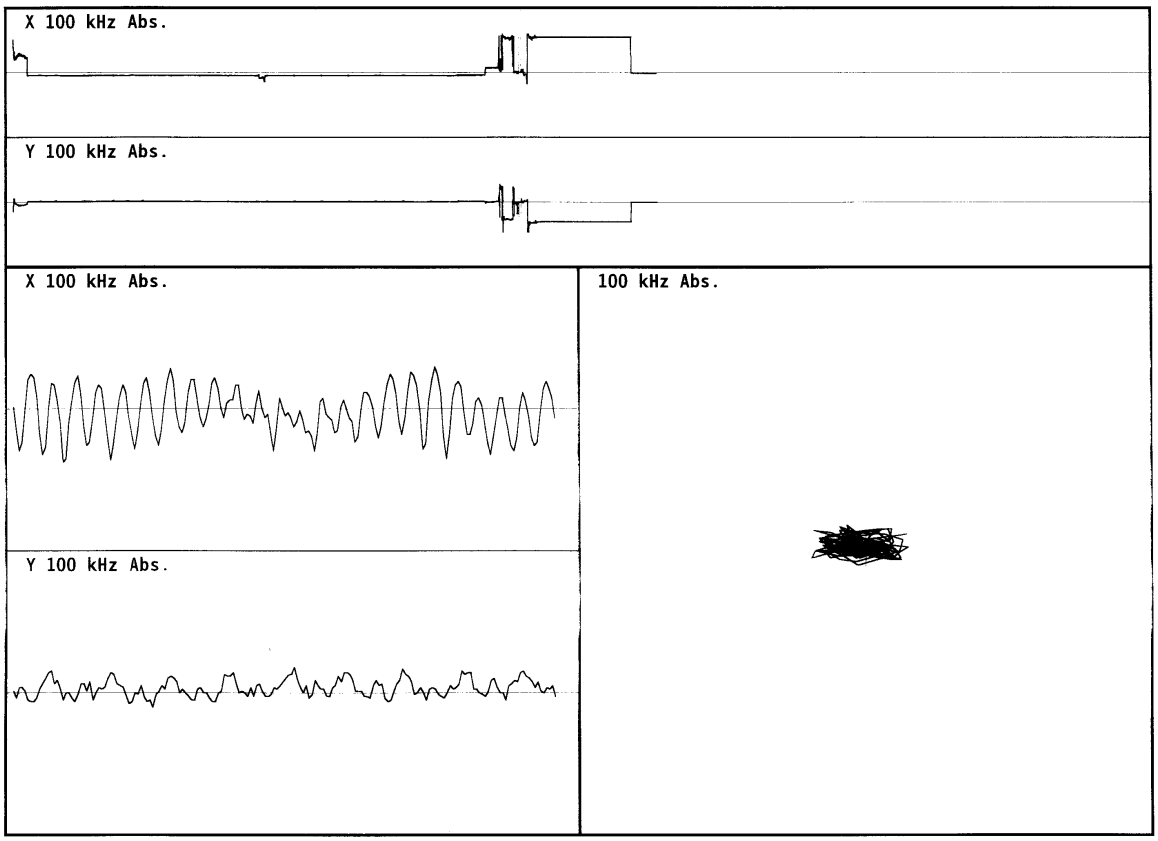

Figure 5-16
Electronic noise

Parasitic Noise

The measurement of parasitic noise is performed on all measurement channels using raw signals (before calibration). The entire data file, with both the inspected tube zone and the Quality Standard, is reviewed for the presence of spikes. These signals differ from dropout signals by the fact that the signal base line does not change.

A spike (see Figure 5-17) is characterized by a discontinuity between two consecutive measurement points with an absolute value of amplitude greater than a defined threshold value expressed as a certain level of the eddy current instrument dynamic range.

$$\left|V_n - V_{n-1}\right| > S_p$$

where: V_n (volts) = signal amplitude at data point *n*

V_{n-1} (volts) = signal amplitude at data point *n-1*

S_p (volts) = threshold amplitude

The threshold amplitude value is an arbitrary value. It has to be low enough to correctly categorize small amplitude parasites and high enough not to categorize as parasitic noise any rapid variation obtained on a high amplitude signal such as an expansion transition.

The acceptability determination consists of measuring the number of spikes per second.

The test results are considered acceptable if the number of spikes per second is less than the threshold value determined in Section 6.

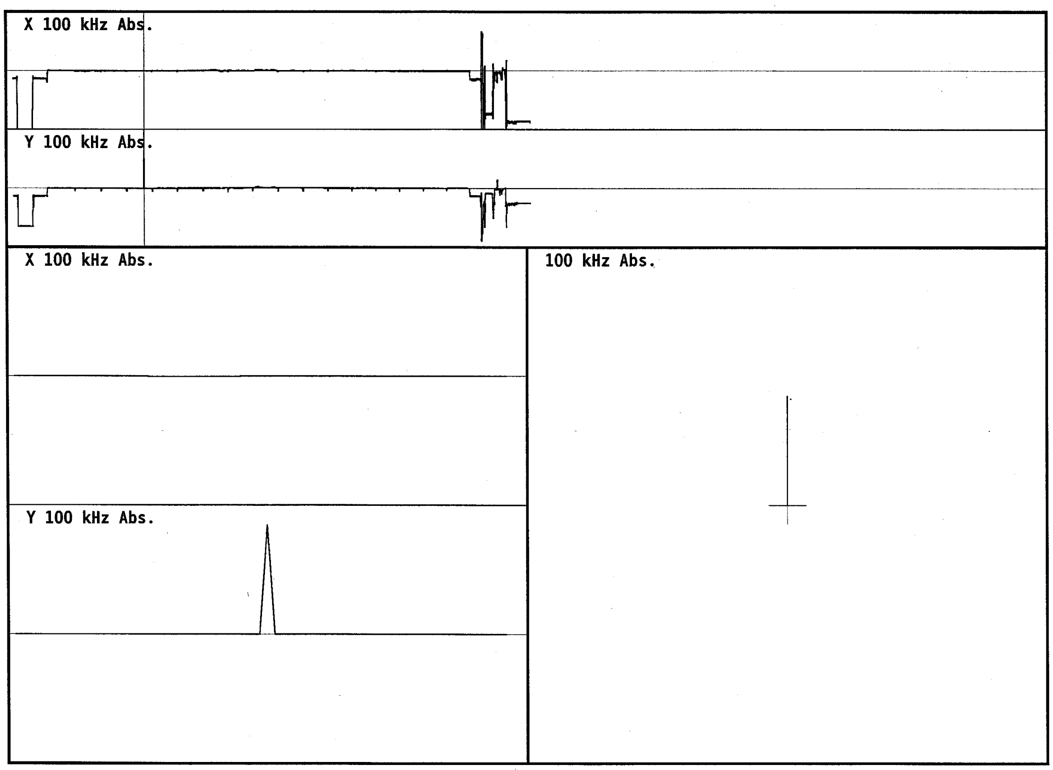

Figure 5-17
Parasitic noise

5.22 Tube Coordinates Verification

Probe position (tube coordinates) verification can be implemented on-line only if both automatic analysis is performed and historical data are available. Although automatic systems do not currently perform the primary data analysis function, this subsection provides examples of test parameters that can be checked, manually or automatically, to verify probe position (tube coordinates).

Assuming that previous inspection results are available and that an automatic analysis is performed, the results from the two inspections can be compared.

Rules concerning "permissible" evolution of the number of flaws, of their amplitudes and phases, their axial positions, dimensions, etc. can be established. Based on those rules and the differences found between two inspections, an automatic alert can be triggered. In the case of differences greater than predefined thresholds, a possible error of probe position would be indicated.

5.23 Review of Quality Parameters Measurements and Verifications

Table 5-2
Summary of quality parameter measurements

Quality Parameter	Reference in Report	Measurement Zone	Frequencies / Channels Verified	Type of Measurement
Tube identification	5.1	File header and/or associated file (summary,…)	N/A	Information comparison
Extent tested – full length	5.3	Entire inspected zone	Low frequency channel	Time (2 tube/air transitions)
Extent tested – partial length	5.3	Entire inspected zone	Low frequency channel	Time (1 tube/air transition), landmark detection
Presence of a calibration standard, e.g. ASME	5.4	Calibration group	N/A	File presence
				Time (between two data files)
				Time (2 tube/air transitions)
Presence of the Quality Standard	5.5	End of data file (acquisition on pull)	Low frequency channel	Time (2 tube/air transitions)
Digitization – loss of bits	5.6	Transition tube/air / Transition air/tube	All data channels	Variation of a value
Saturation	5.7	Calibration standard / Quality standard / Expansion transition / U-bend	All data channels	Value of $X(t)$ and/or $Y(t)$
Measurement on reference defects	5.8	Quality standard	All data channels	Amplitude, phase
Presence of eddy current signals	5.9	Quality standard	All data channels	Phase
Digitization rate	5.10	Quality standard / inspected zone	Reference frequency in differential mode	Time (number of samples)

Summary of quality parameter measurements (continued)

Quality Parameter	Reference in Report	Measurement Zone	Frequencies/ Channels Verified	Type of Measurement
Speed variation	5.11	Inspected zone	Low frequency channel in absolute mode	Time (number of samples)
Probe wiring	5.12	Quality standard	Reference frequency channel	Time
Coil arrangement	5.13	Quality standard	All frequencies in absolute mode	Amplitude
Symmetry of signal in differential mode	5.14	Quality standard	All frequencies in differential mode	Amplitude
Centering of the probe	5.15	Quality standard	Reference frequency in differential mode	Amplitude
Imbalance of the probe in differential mode	5.16	Air area and sound area of calibration standard	All frequencies in differential mode	Amplitude
Offset	5.17	Quality standard	All data channels	Amplitude
Offset variation	5.18	Quality standard	All data channels	Amplitude
System dynamics	5.19	Quality standard	All data channels	Amplitude
Signal dropout	5.20	Entire inspected zone	All frequencies in differential mode	Amplitude
Signal-to-noise ratio - electronic noise	5.21	Quality standard	All data channels	Amplitude
Signal-to-noise ratio - spikes	5.21	Quality standard & inspected zone	All data channels	Amplitude variation
Position verification	5.22	Inspected zone	Reference frequency channel	Amplitude, phase, altitude, length

Table 5-3 shows the need for a Quality Standard to maximize the number of quality parameters that can be measured.

Table 5-3
Applicability of standards for performing measurement and verification of data quality

Quality Parameter	Calibration Standard Recording (e.g. ASME)	SG tube alone	SG tube and Quality Standard recording
Tube identification	Applicable	Applicable	Applicable
Extent tested	Not applicable	Applicable	Applicable
Presence of a calibration standard (file)	Not applicable	Applicable	Applicable
Presence of a calibration standard (time)	Not applicable	Applicable	Applicable
Presence of a calibration standard (signal)	Applicable	Not Applicable	Not applicable
Presence of the Quality Standard	Not applicable	Not Applicable	Applicable
Digitization – loss of bits	Applicable	Applicable	Applicable
Saturation	Applicable	Applicable	Applicable
Measurement on reference defects	Not applicable	Not Applicable	Applicable
Presence of eddy current signals	Not applicable	Not Applicable	Applicable
Digitization rate	Not applicable	Not Applicable	Applicable
Speed variation	Not applicable	Not Applicable	Applicable
Probe wiring	Not applicable	Not Applicable	Applicable
Coil arrangement	Not applicable	Not Applicable	Applicable
Symmetry of signal	Not applicable	Not Applicable	Applicable
Centering of the probe	Not applicable	Not Applicable	Applicable
Imbalance of the probe	Not applicable	Not Applicable	Applicable
Offset and Offset variation	Not applicable	Not Applicable	Applicable
System dynamics	Not applicable	Not Applicable	Applicable
Signal dropout	Not applicable	Not Applicable	Applicable
Signal-to-noise ratio - electronic noise	Not applicable	Not Applicable	Applicable
Signal-to-noise ratio - parasite noise	Not applicable	Not Applicable	Applicable
Position verification	Not applicable	Applicable	Applicable

6 ACCEPTANCE CRITERIA

Acceptance criteria and associated thresholds are defined for each data quality parameter previously discussed. These criteria are considered preliminary since they are based on initial investigations of limited data and without the use of a Quality Standard. Ongoing work will provide additional data and allow for refinement of the proposed acceptance criteria. The assumptions for the establishment of the preliminary criteria are derived from:

- Statistical analysis performed on data recordings from worldwide industry data,
- EPRI recommendations [2],
- Technical limits of currently used equipment and procedures,
- Experience.

6.1 Tube Identification

The acquired data file shall include information specific to the inspection being performed. The following information shall be provided and shall be verified to be correct:

- Nuclear power plant (NPP) name,
- Unit number for this NPP,
- Steam generator designation,
- Tube numbering convention (i.e. respective row or line number),
- Column or tube number,
- Tube row/column coordinates,
- Tube of given row/column number is not plugged or in some other way inaccessible,
- Probe entry side.

Additional verifications shall be performed using the data from the test summary or other external sources. Verifications shall be performed to confirm that :

- Probe type and serial number correspond to SG model and inspection techniques being used
- Calibration standard type and serial number correspond to SG model and inspection techniques being used

6.2 Extent Tested

Full Length

Testing with a bobbin coil probe has been the primary method of examining steam generator tubes . In most cases, the entire tube length is examined.

The recording of the data from the tube to be tested shall include the entire tube extent. It must include both air/tube and tube/air transitions corresponding to the probe entry into and exit from the tube being tested, as shown in the example in Figure 6-1.

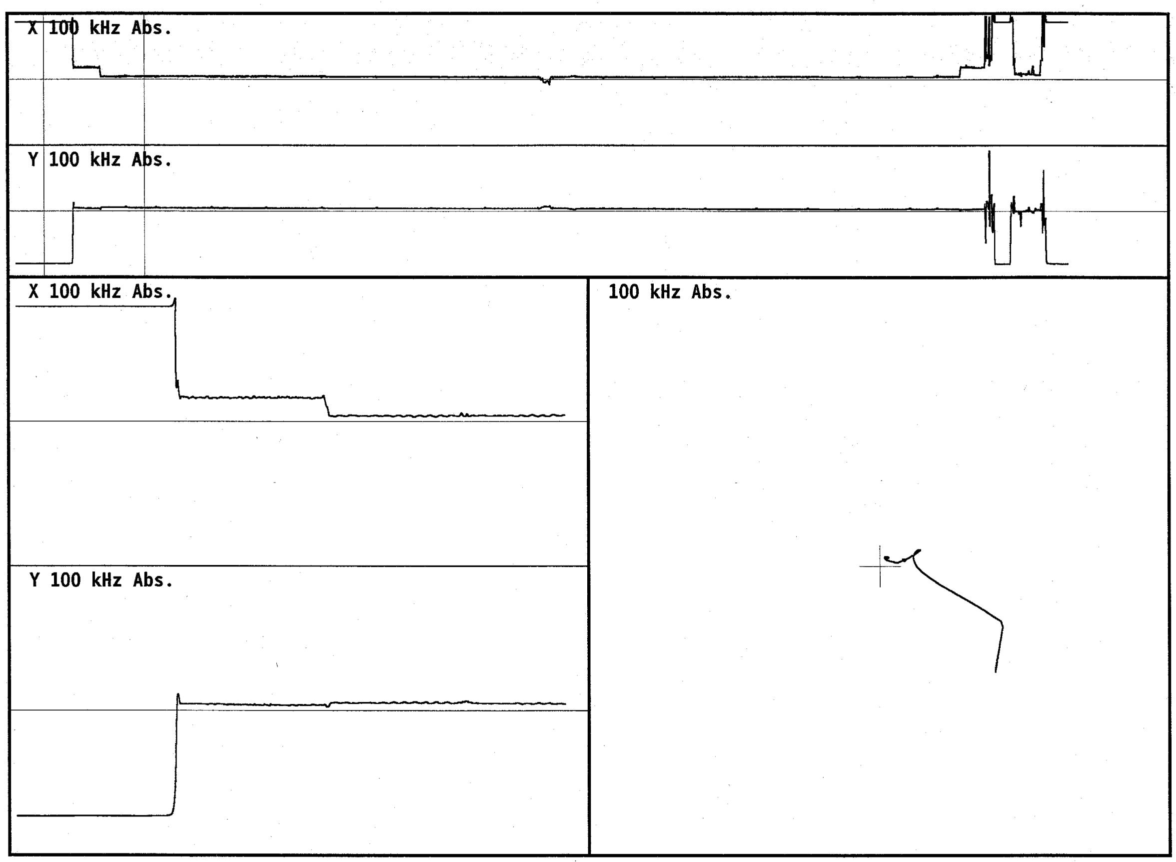

Figure 6-1
Acceptable full length recording

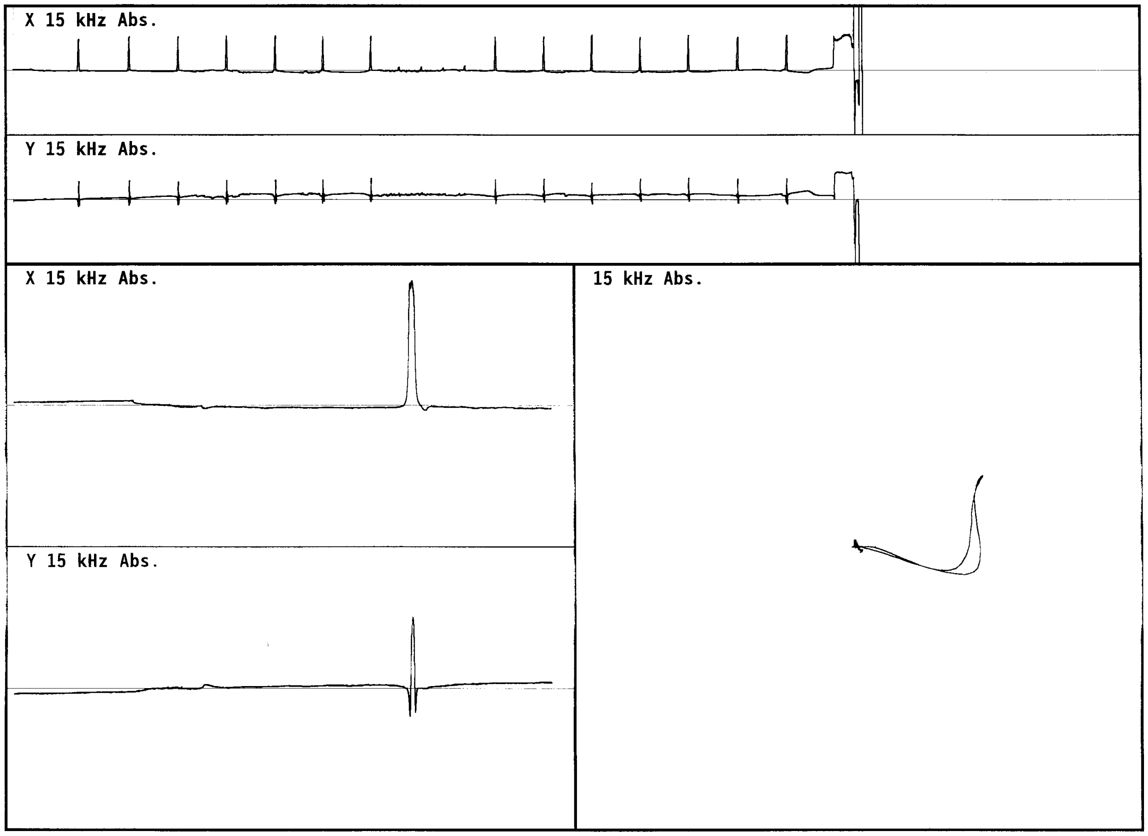

Figure 6-2
Unacceptable incomplete recording : absence of the transition air/tube

Figure 6-2 shows a lack or a loss of data in one portion of the recording of the examined tube. This recording is not acceptable as this loss of information does not allow signal analysis and can conceal one or several indications.

Partial Length

When recording of the inspection area includes a part length examination of the probe entry leg of the tube, it shall include the tube/air transition corresponding to the exit of the probe from the tube, as shown in Figure 6-3.

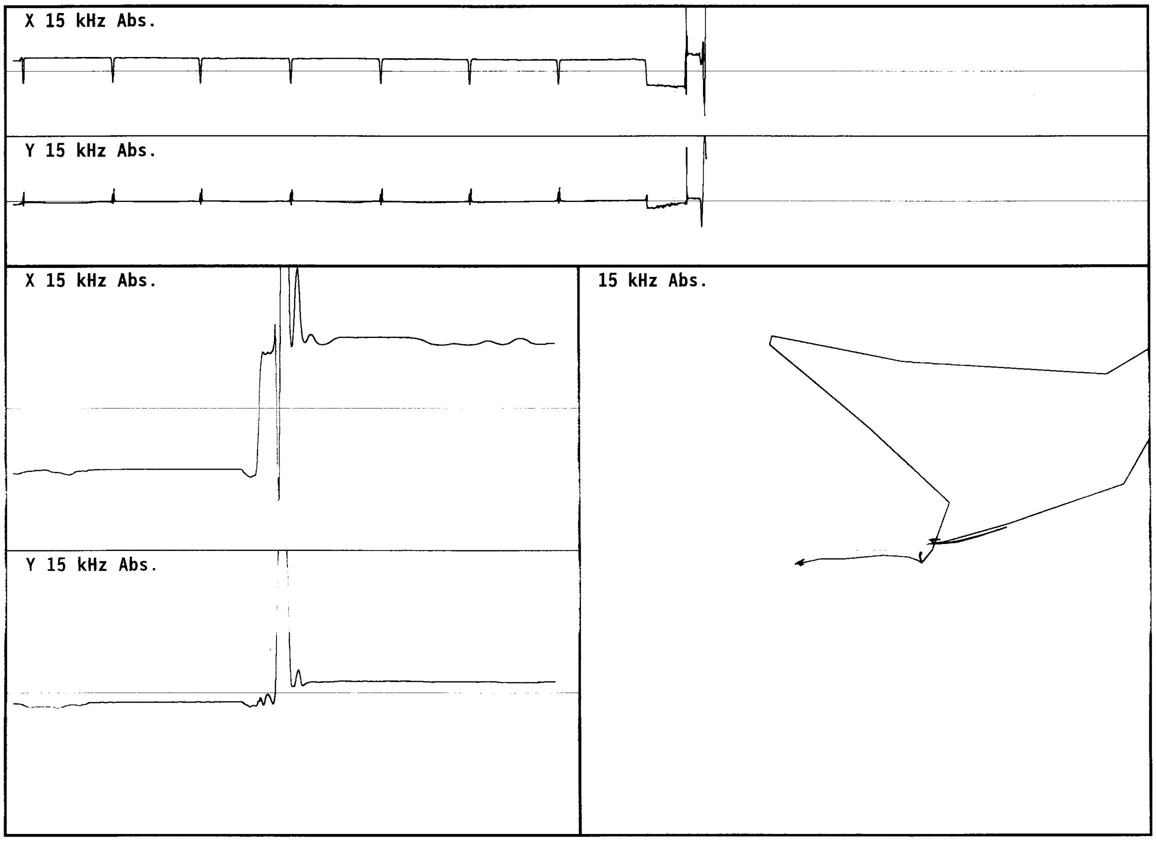

Figure 6-3
Acceptable partial length recording

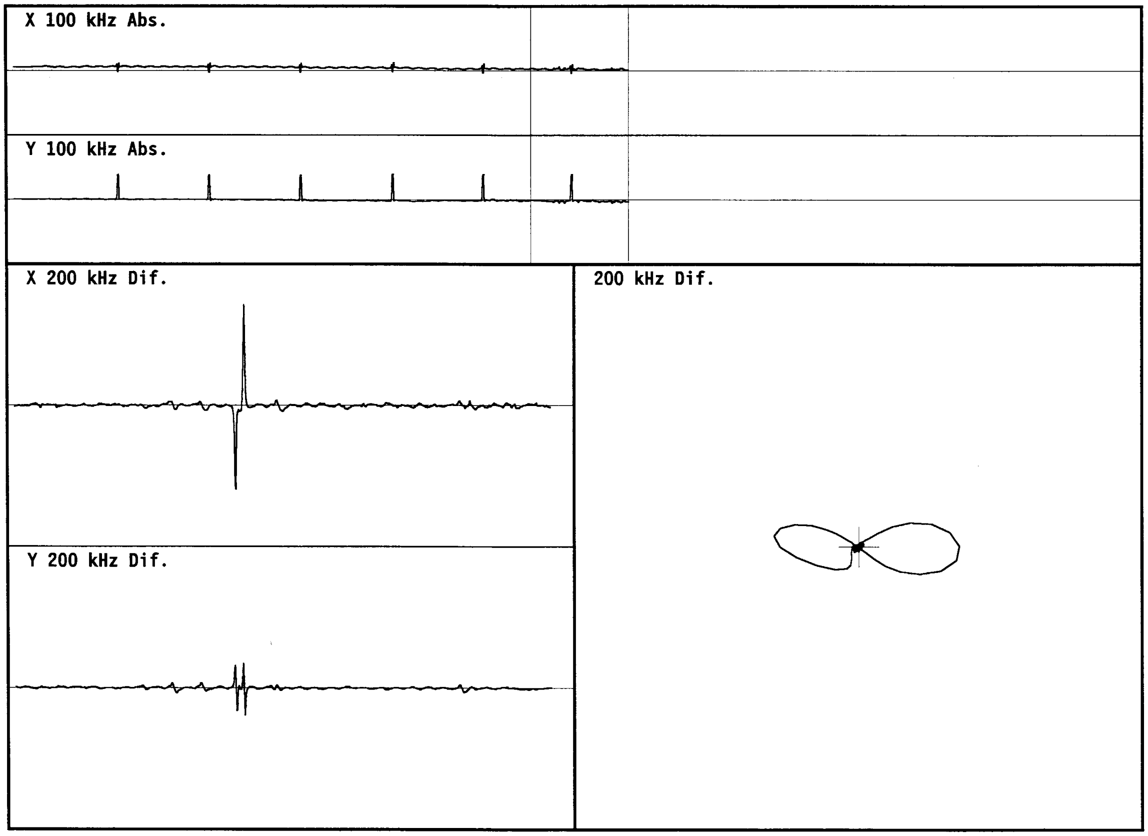

Figure 6-4
Unacceptable recording : absence of the transition tube/air

Figure 6-4 shows an example with a loss or a lack of data near the end of the recording, in the rolled portion of the tube. This recording is not acceptable as this loss of information does not allow signal analysis and can conceal one or several indications.

Landmark detection

The test is considered acceptable if the number of support plates detected is equal to the theoretical number of support plates in the inspection area.

Due to different possible responses of different support structures, it will be rather difficult to establish one single rule concerning this test.

Although possible, this verification is quite difficult to implement and it will not be considered any further.

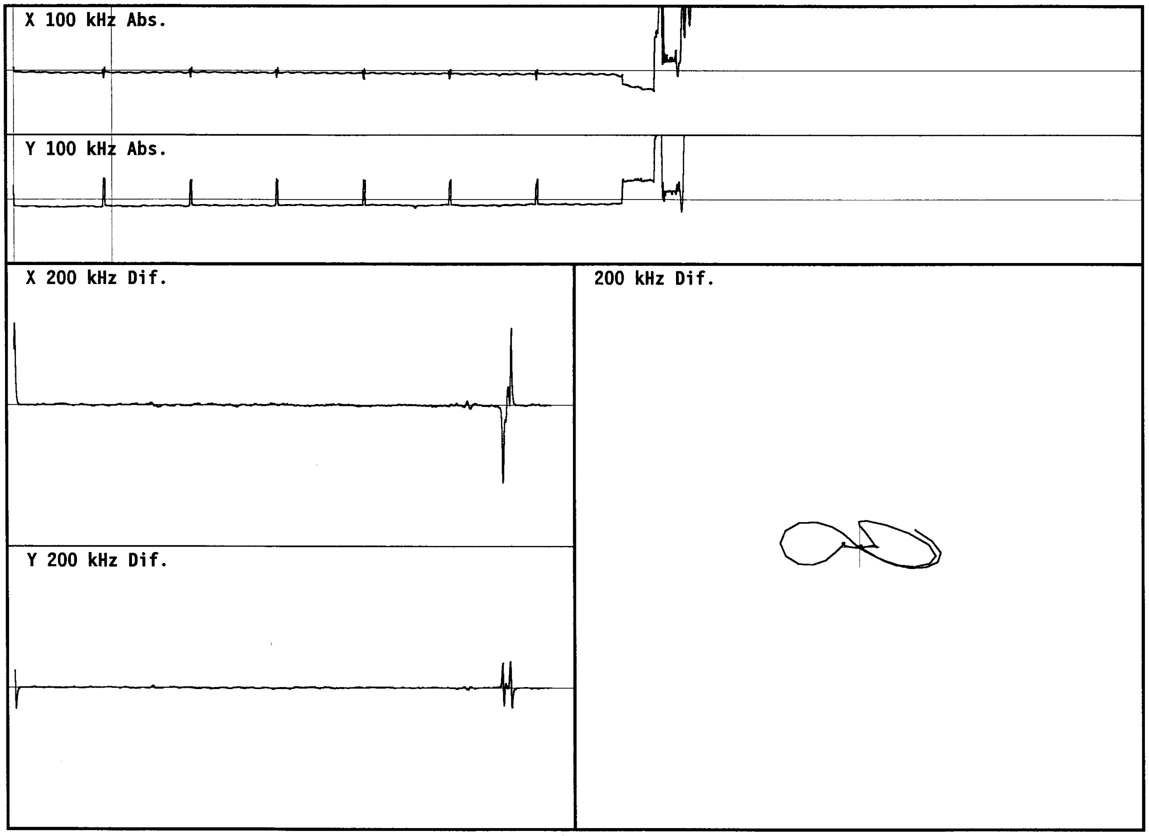

Figure 6-5
Incomplete recording : absence of the last support plate

Figure 6-5 shows a loss or a lack of data in the recording of the U-bend portion of the examined tube. The necessary overlap of data will not be possible as the last tube support and the U-bend do not appear on the recording. This recording is not acceptable as this loss of information does not allow signal analysis and can conceal one or several indications.

6.3 Presence of a Calibration Standard

Calibration standard shall be recorded at the beginning and end of each cal group and at least once every four hours. The four-hour interval starts following the latest acceptable calibration for each cal group.

Recording of the entire calibration standard is required. It must include one air/calibration standard transition and one calibration standard /air transition corresponding to the probe entry into and exit from the calibration standard, as shown on the recording in Figure 6-6.

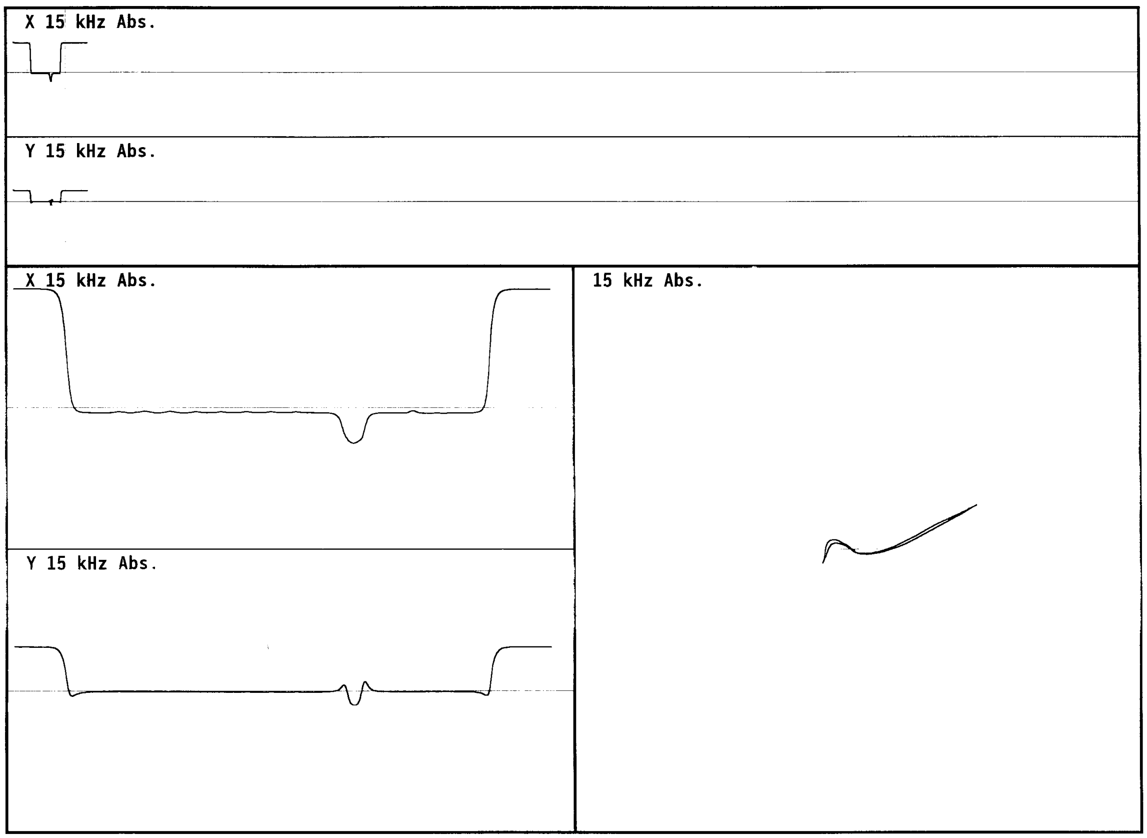

Figure 6-6
Acceptable calibration standard recording

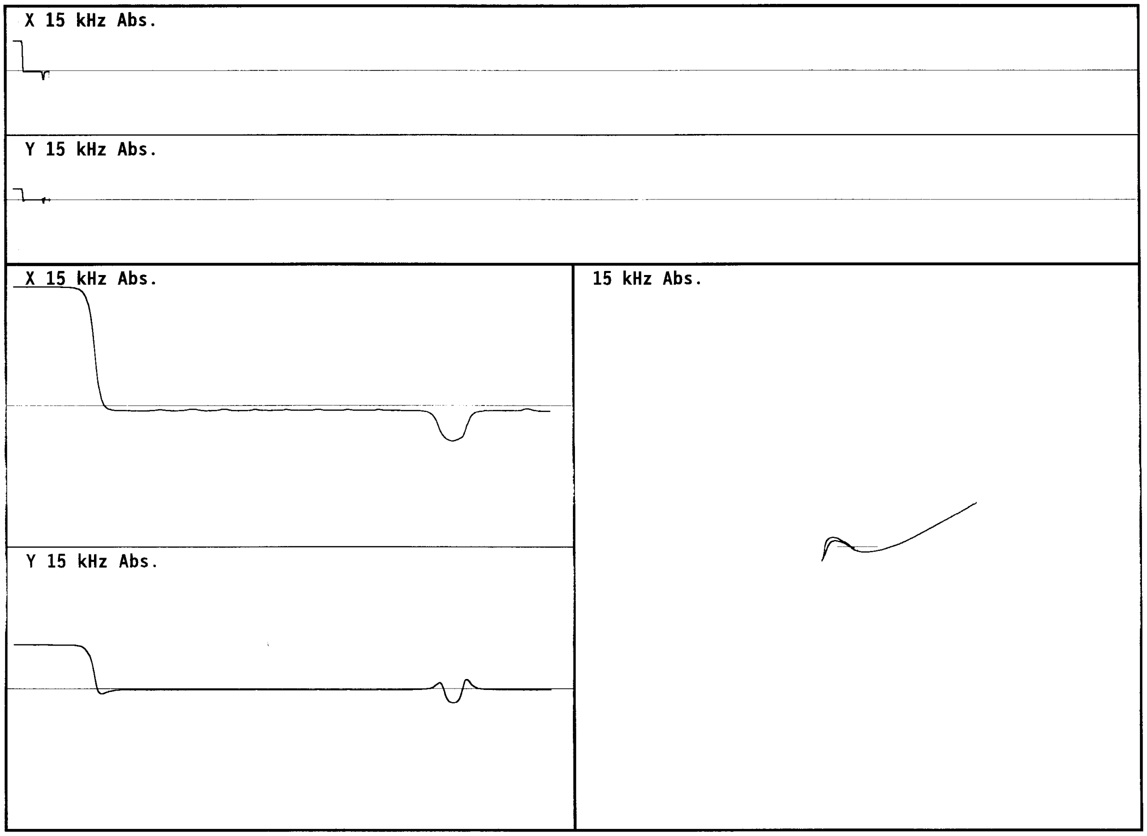

Figure 6-7
Unacceptable calibration standard recording

Figure 6-7 shows a loss or a lack of data in the end of the recording of a calibration standard. This recording is not acceptable as several signals from reference defects, used for calibration, mixes or phase /depth calibration curves may be missing or incomplete.

6.4 Presence of the Quality Standard

The complete presence of the Quality Standard is necessary for the majority of the data quality checks (see Tables 5-2 and 5-3).

Recording of the entire Quality Standard is required. It must include one air/Quality Standard transition and one Quality Standard/air transition corresponding to the probe entry into and exit from the Quality Standard, as shown in Figure 6-8.

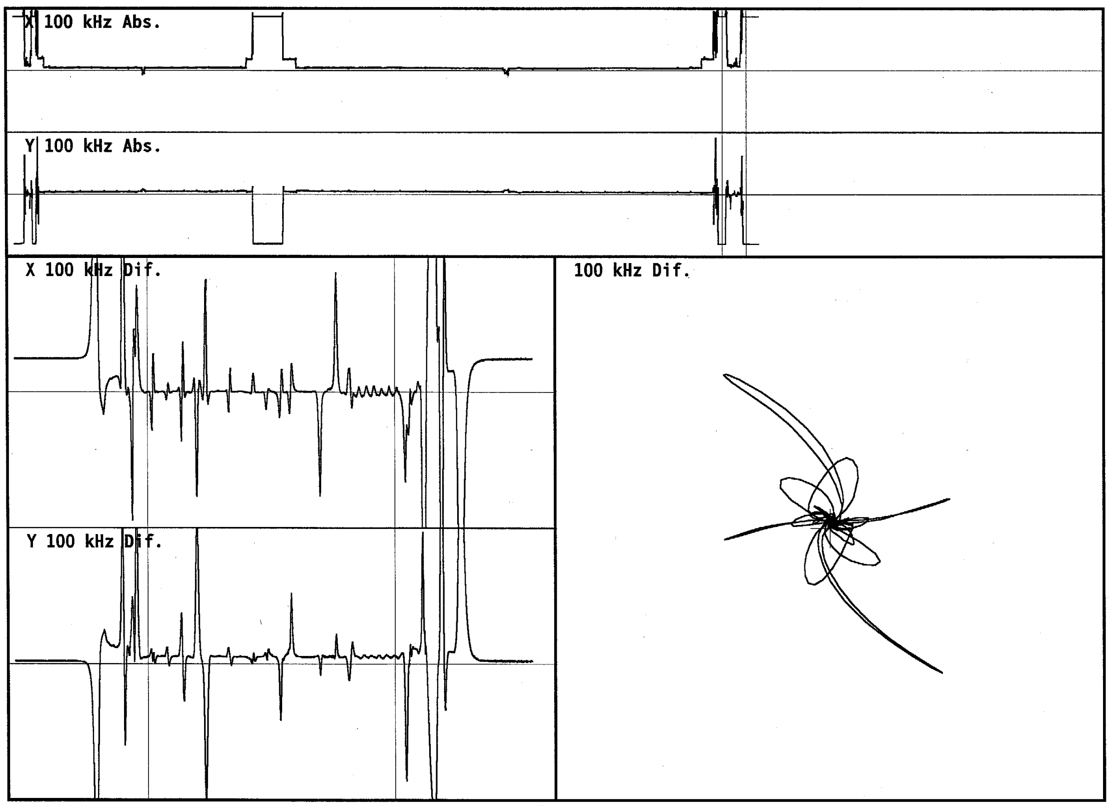

Figure 6-8
Acceptable Quality Standard recording

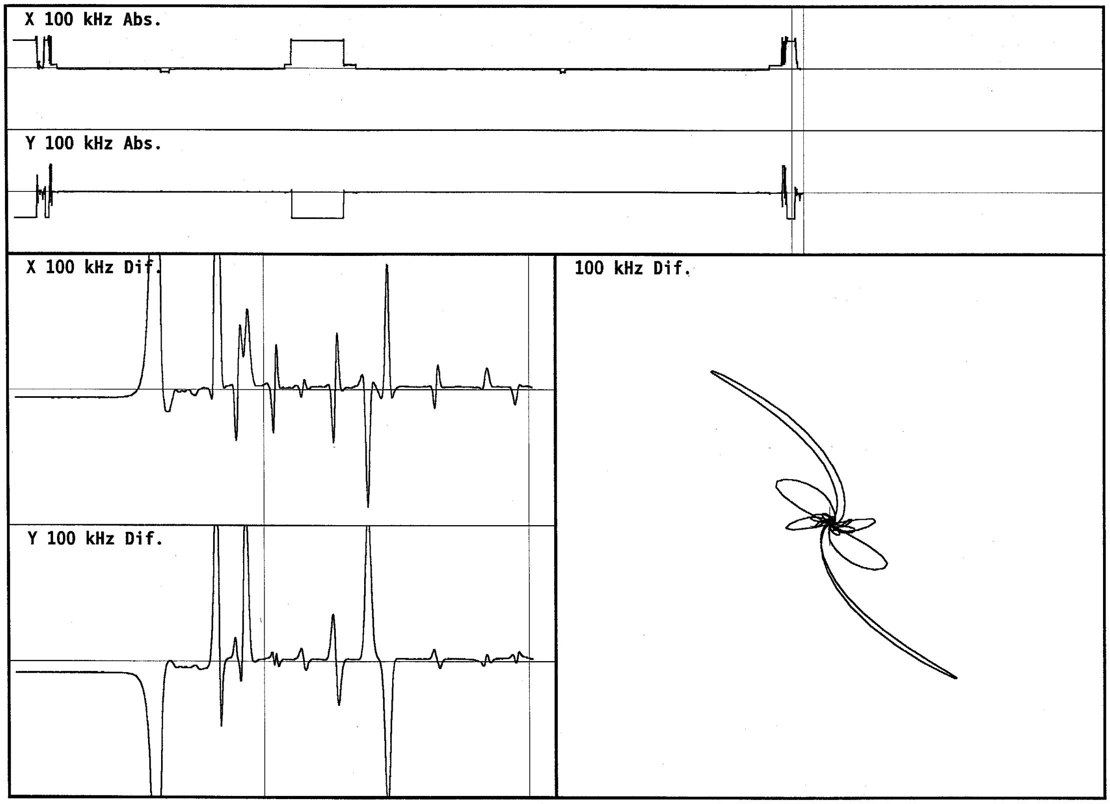

Figure 6-9
Unacceptable Quality Standard recording

Figure 6-9 shows a loss or a lack of data in the end of the recording of the Quality Standard. This recording is not acceptable as several signals from reference defects, used for data quality checks may be missing or incomplete.

6.5 Digitization – Loss of Bits

The status of all data bits shall change at least once on any channel.

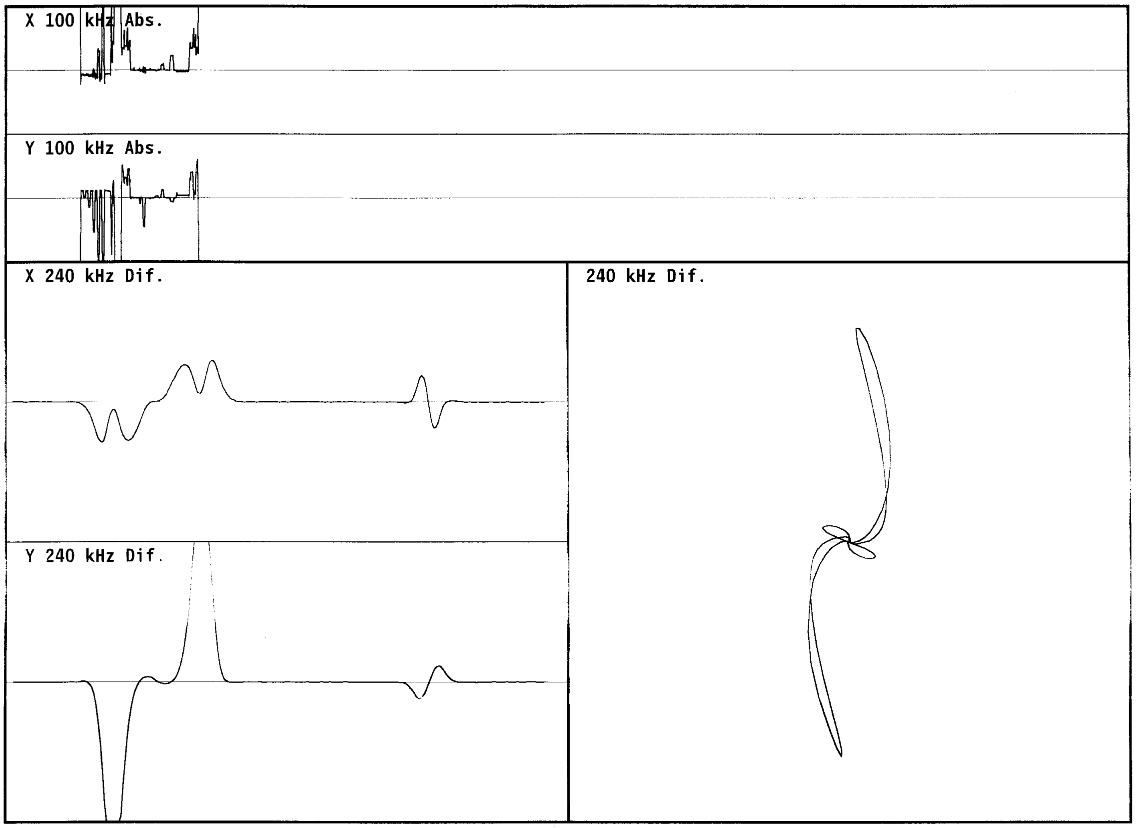

Figure 6-10
Acceptable recording without loss of bits

When observing the time base display of the signals or the Lissajous pattern shown in Figure 6-10, the mathematical continuity of the functions displayed is noted. This is characteristic of the absence of any loss of bits.

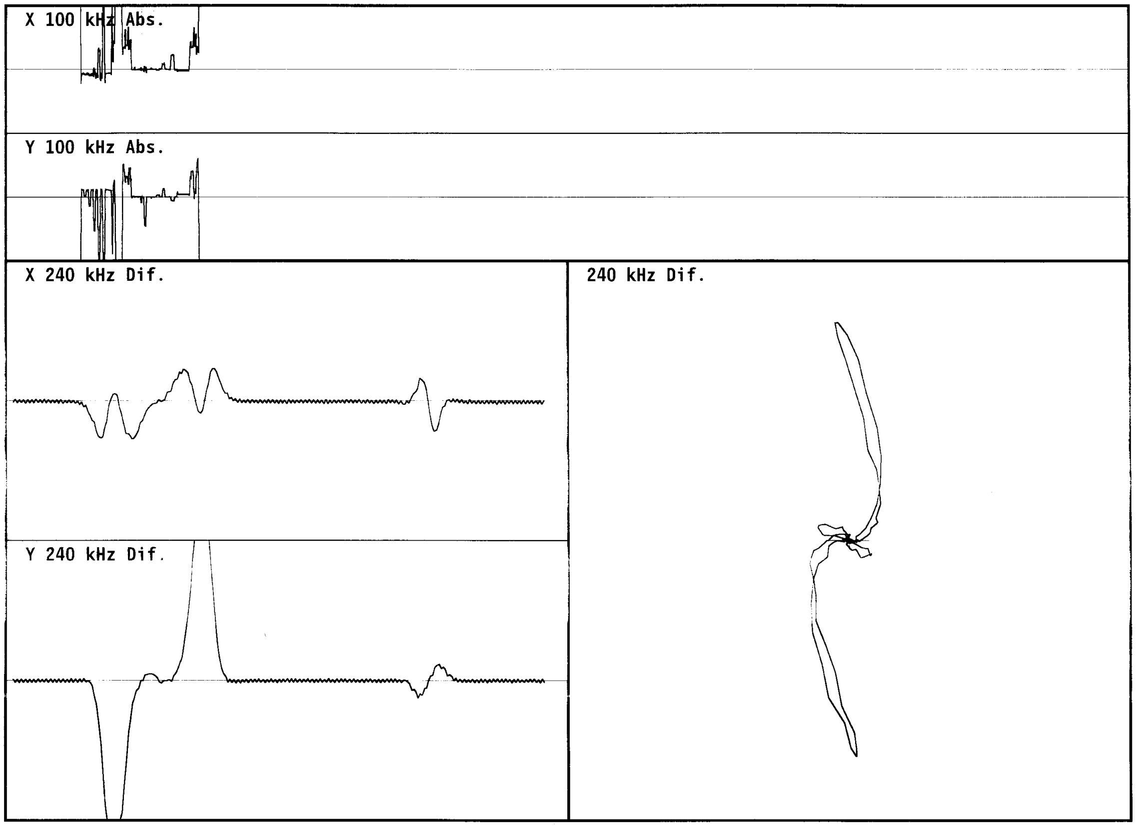

Figure 6-11
Unacceptable recording with loss of bits (LSB)

Figure 6-11 and Figure 6-12 show losses of bits in two recordings. Several mathematical discontinuities can be observed in the various displays. Depending on the ratio between the value of the lost bit and the amplitude (A) of the signal, these recordings are not acceptable for the following reasons :

- “Noisy” signal if the ratio is low
- “jagged” signal, for an average value of the ratio
- A decrease in the signal amplitude if the ratio is high

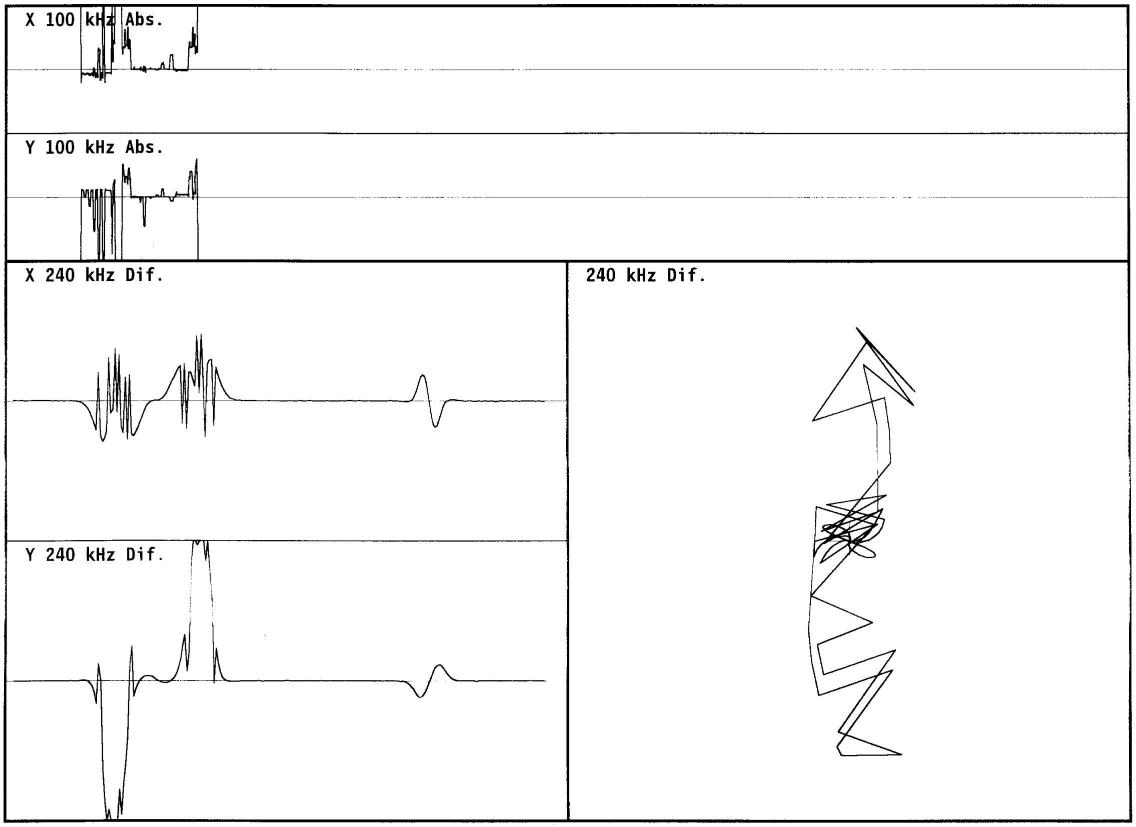

Figure 6-12
Unacceptable recording with loss of bits (MSB)

6.6 Saturation

The presence of saturation on a large number of measurement points may conceal an indication of a degradation.

The presence of saturation on one or both ends of a signal means that it is not possible to correctly measure either the amplitude (underestimated), or the phase (shifted and cannot be related to the initial calibration phase set-up) as shown in Figure 6-13.

To be considered acceptable, none of the measurement points of the inspected areas shall show saturation.

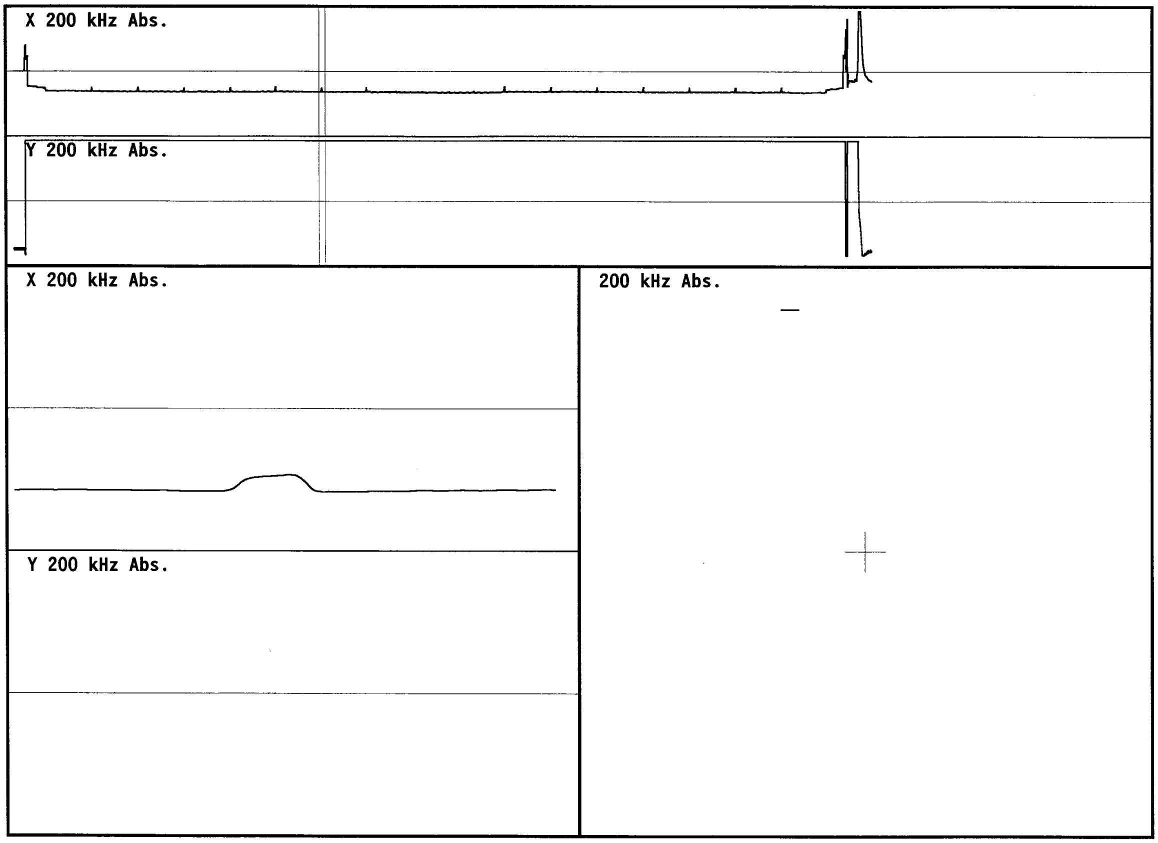

Figure 6-13
Unacceptable recording containing saturation

Figure 6-13 shows a saturated Y(t) component on the whole length of the recording corresponding to the examined tube. This recording is not acceptable as this loss of information does not allow signal analysis and can conceal one or several indications.

6.7 Measurement on Reference Defects

Assuming injected frequencies $f_1, f_2, \ldots, f_n$ where $f_1 > f_2 > \ldots > f_n$, the phase shifts between the through-wall defect signal and any OD defect signal $\Delta\varphi_1, \Delta\varphi_2, \ldots, \Delta\varphi_n$ have to be:

$$\Delta\varphi_1 > \Delta\varphi_2 > \ldots > \Delta\varphi_n$$

Data that does not meet this criterion shall be rejected.

6.8 Presence of Eddy Current Signals

The test is considered acceptable if the measured phase difference ($\Delta\varphi$) between one ID defect signal and one OD defect signal from the Quality Standard is not null at all frequencies, indicating that all frequencies are operational.

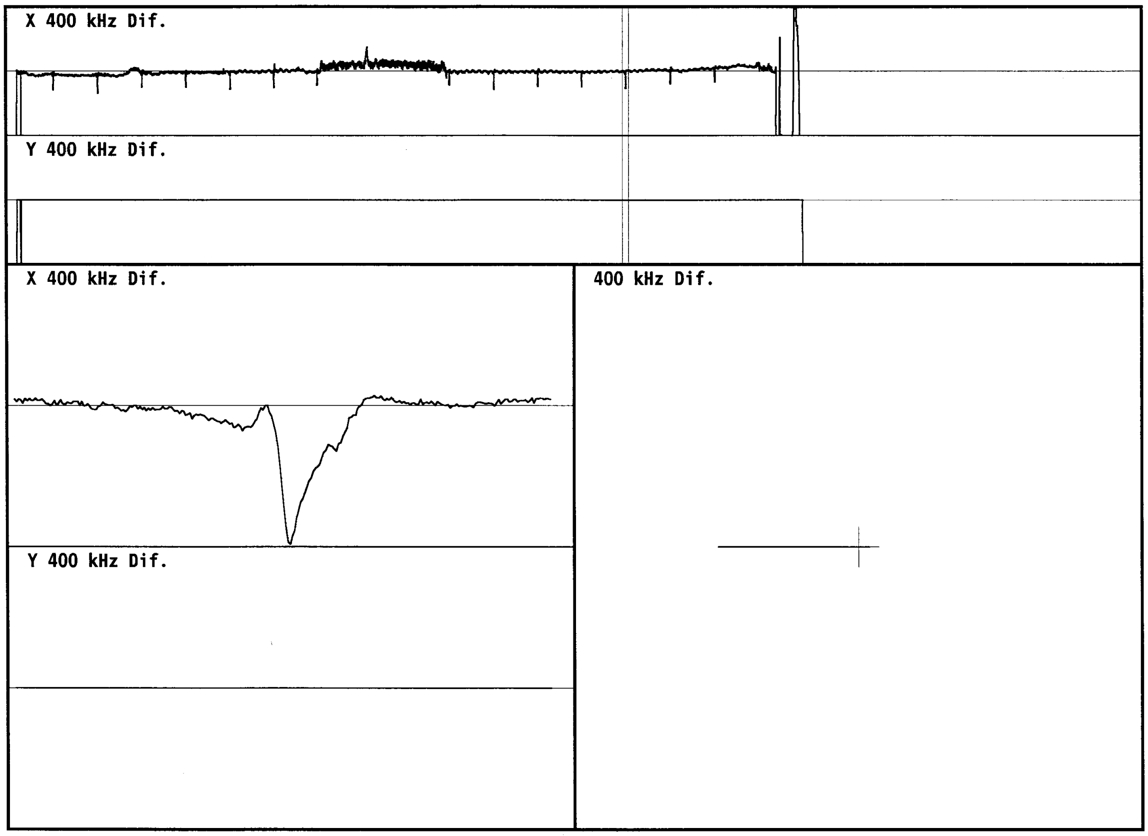

Figure 6-14
Unacceptable recording containing loss of channels

Figure 6-14 shows the absence of the Y(t) component of the signal at 400kHz on the entire length of the recording. This recording is not acceptable as this loss of information does not allow signal analysis and can conceal one or several indications.

6.9 Digitization Rate

The digitization of the eddy current signal over time results in a loss of information regarding the signal shape. The magnitude of the information loss must be controlled to avoid detrimental effects on the measurements of the amplitude and phase of the defect signal.

The ASME code requires that the digitization rate shall be greater than or equal to 30 points per inch.

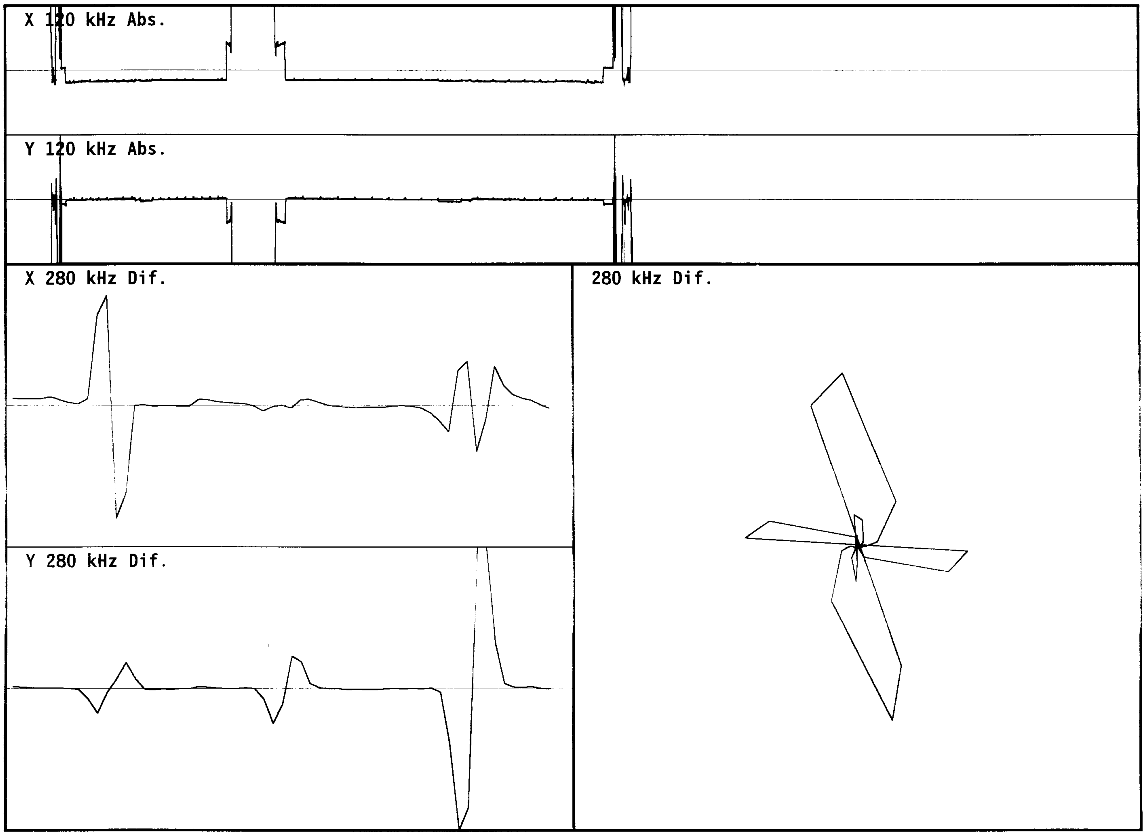

Figure 6-15
Unacceptable recording with low digitization rate

When applying the method described in Section 5 for the measurement of the digitization rate, Figure 6-15 shows an example of a recording obtained with a digitization rate lower than the recommended one. This recording is not acceptable as the poor definition of signals which results from this low digitization rate does not allow accurate measurement of the amplitude and phase of the signals.

6.10 Probe Speed Variation

In order to make it possible to precisely locate flaws with regard to geometrical events in the tube such as tube expansion transitions or support plates, the speed of the probe should be constant throughout the inspection area (SG tube). Verifying the speed in the calibration standard is not a representative measurement as the standard is too short.The current technology of pushers with speed control should enable this constancy to be guaranteed to better than 10% of the nominal value.

The variation in probe speed in the inspection area (SG tube) shall be less than or equal to 10% of the nominal value in the straight section.

6.11 Probe Wiring

An inversion on the wiring of the two measurement coils of the probe has minor consequences on the quality of data.

No acceptance criterion is linked to this test.

6.12 Probe Flux or Coil Arrangement

Generally, an absolute signal obtained with a bobbin coil probe does not feature a secondary lobe, see Figure 6-16. Selecting an acceptance criterion of slightly less than 100% allows the conformity of the flux to be verified without the effect of slight signal variations or of mutual induction between coils.

The amplitude of the main lobe must be greater than or equal to 90% of the total amplitude of the reference defect for all test frequencies in absolute mode.

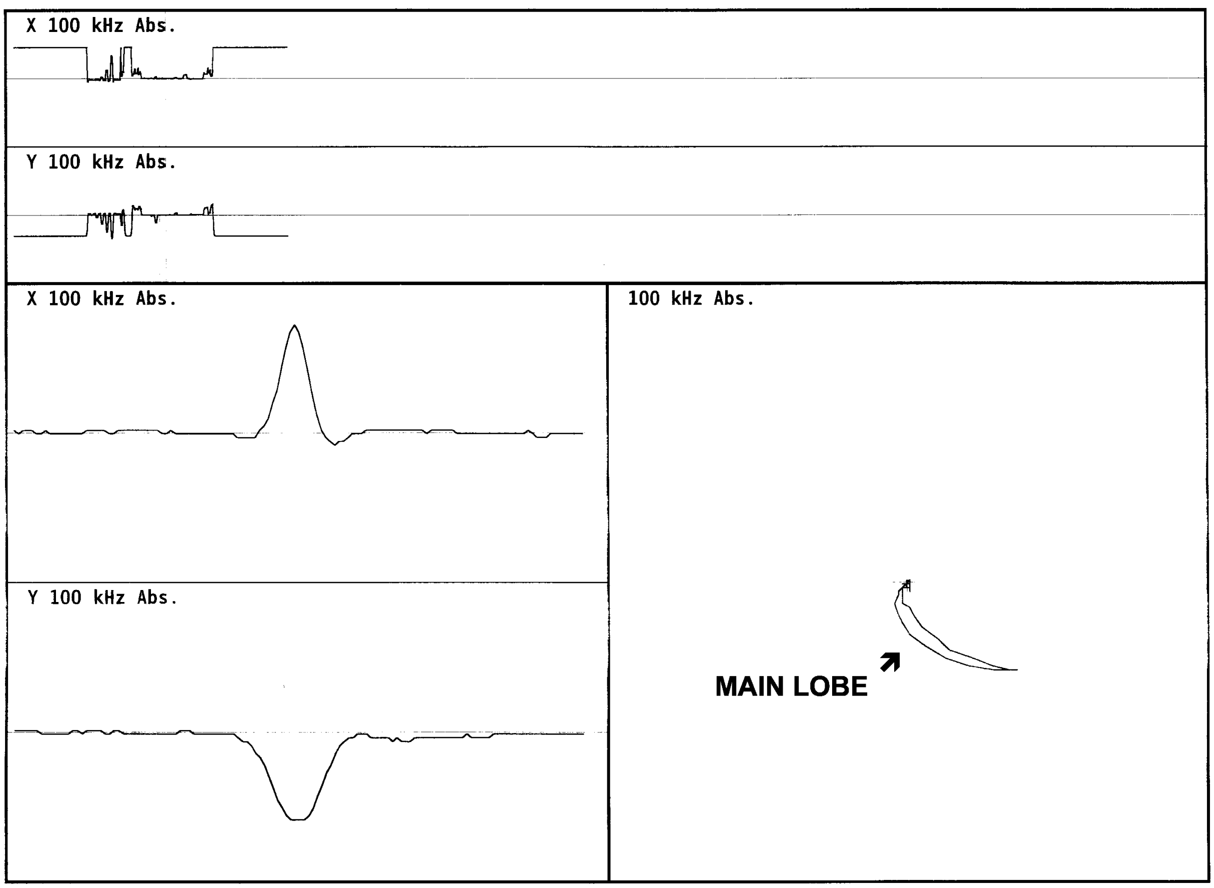

Figure 6-16
Acceptable recording, indicating correct arrangement of coils

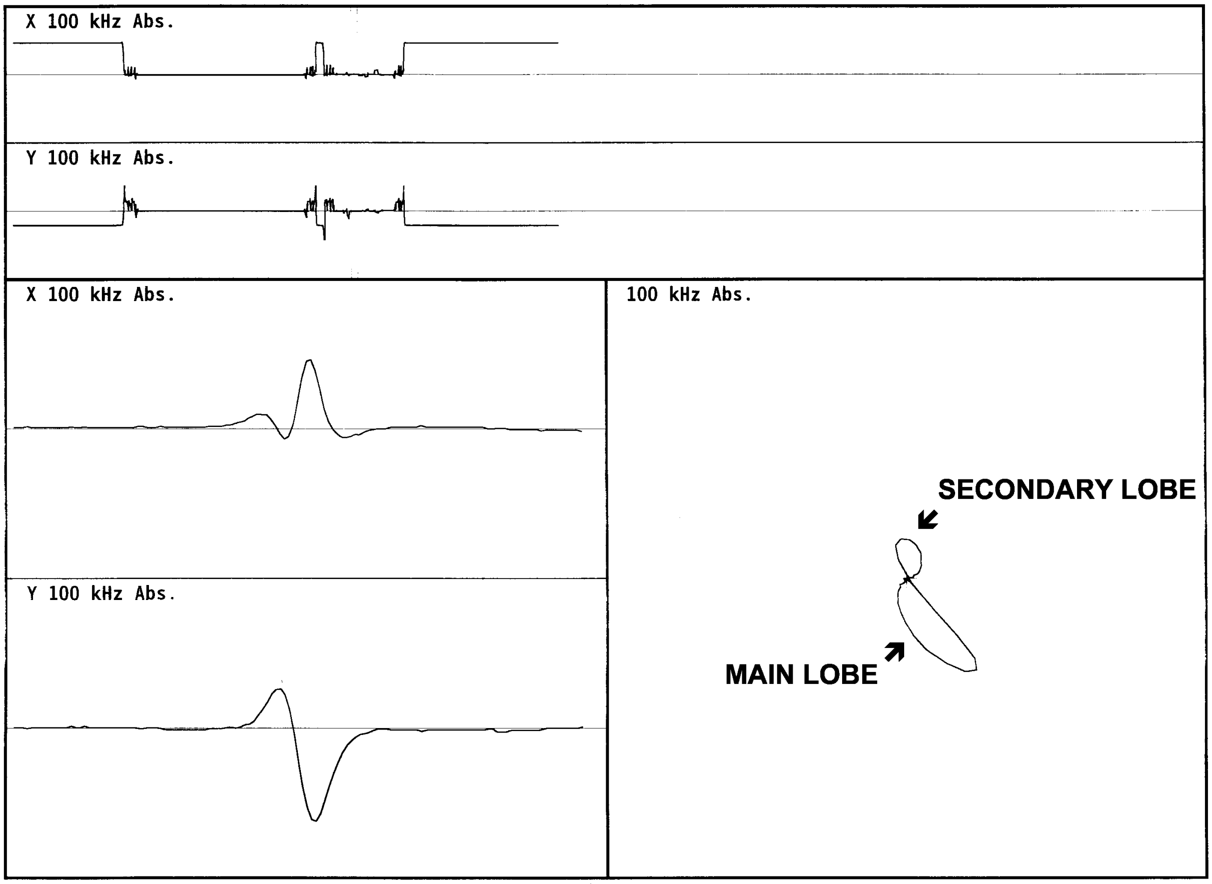

Figure 6-17
Unacceptable recording, indicating wrong arrangement of coils

The recording in Figure 6-17 shows a wrong wiring of the probe coils. This recording is not acceptable as absolute mode signals are distorted. As a result :

- Correct calibration is not possible, if the recording is that of a calibration standard,
- A comparison with previous recordings of the same tube is not possible.

6.13 Symmetry of a Differential Signal

Generally, a differential signal obtained with a bobbin coil probe displays two identical and symmetrical lobes, as shown in Figure 6-18. The acceptance criterion is selected to ensure that the two coils of the probe are equal and allow a correct differential measurement.

Signal dissymmetry, calculated using the method described in Section 5, must be less than or equal to 20% for all the test frequencies in differential mode.

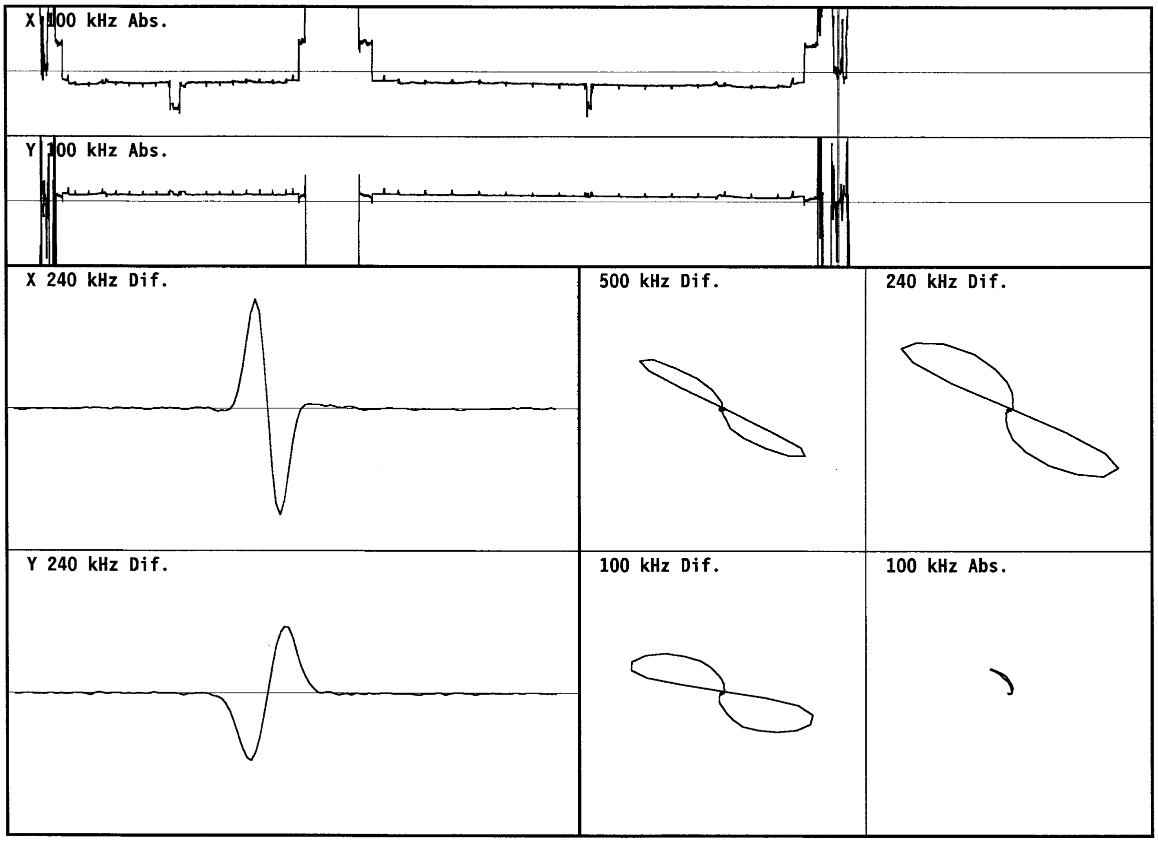

Figure 6-18
Acceptable recording without dissymmetry of differential signals

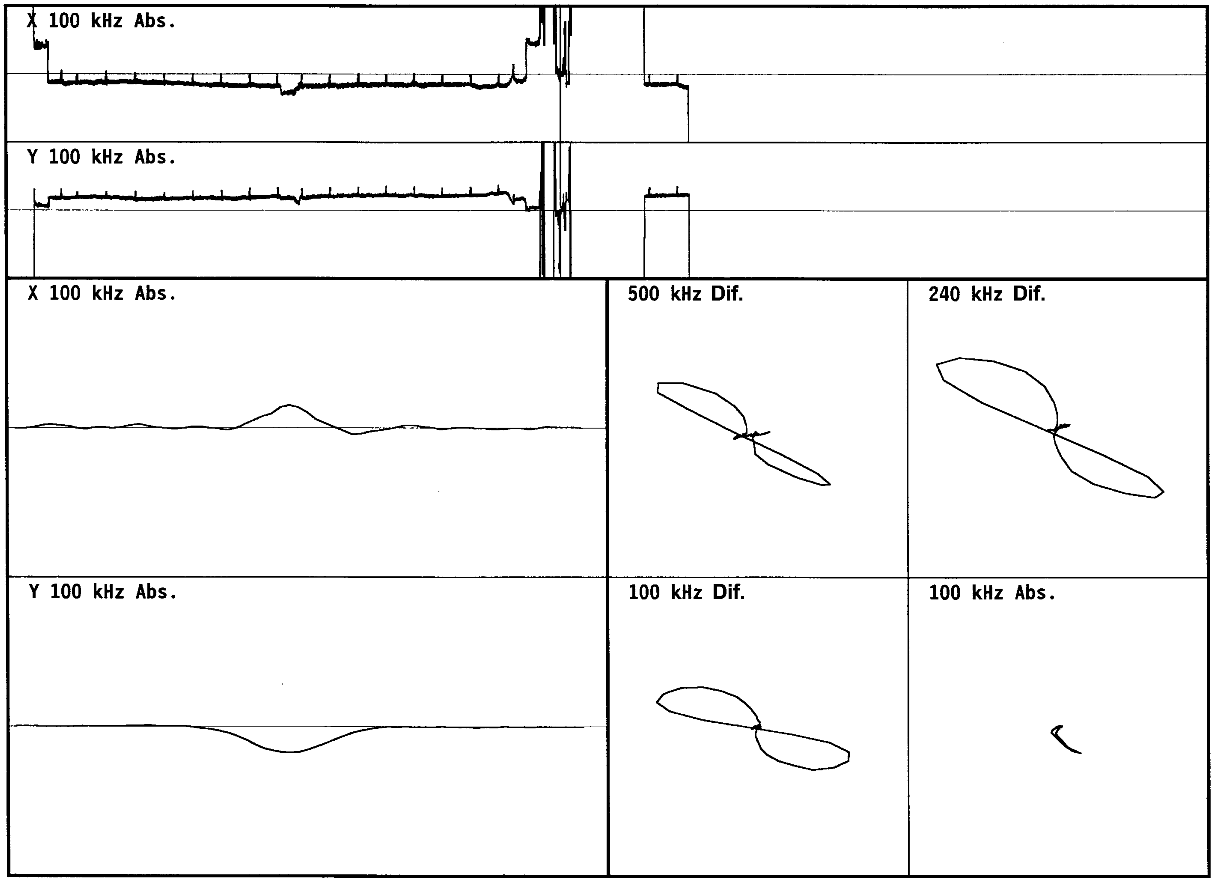

Figure 6-19
Unacceptable recording with dissymmetry of differential signals

The recording in Figure 6-19 shows dissymmetric differential signals at 500 kHz and 240 kHz. This recording is not acceptable as these signals are distorted and that consequently, the comparison with previous recordings of the same tube is not possible.

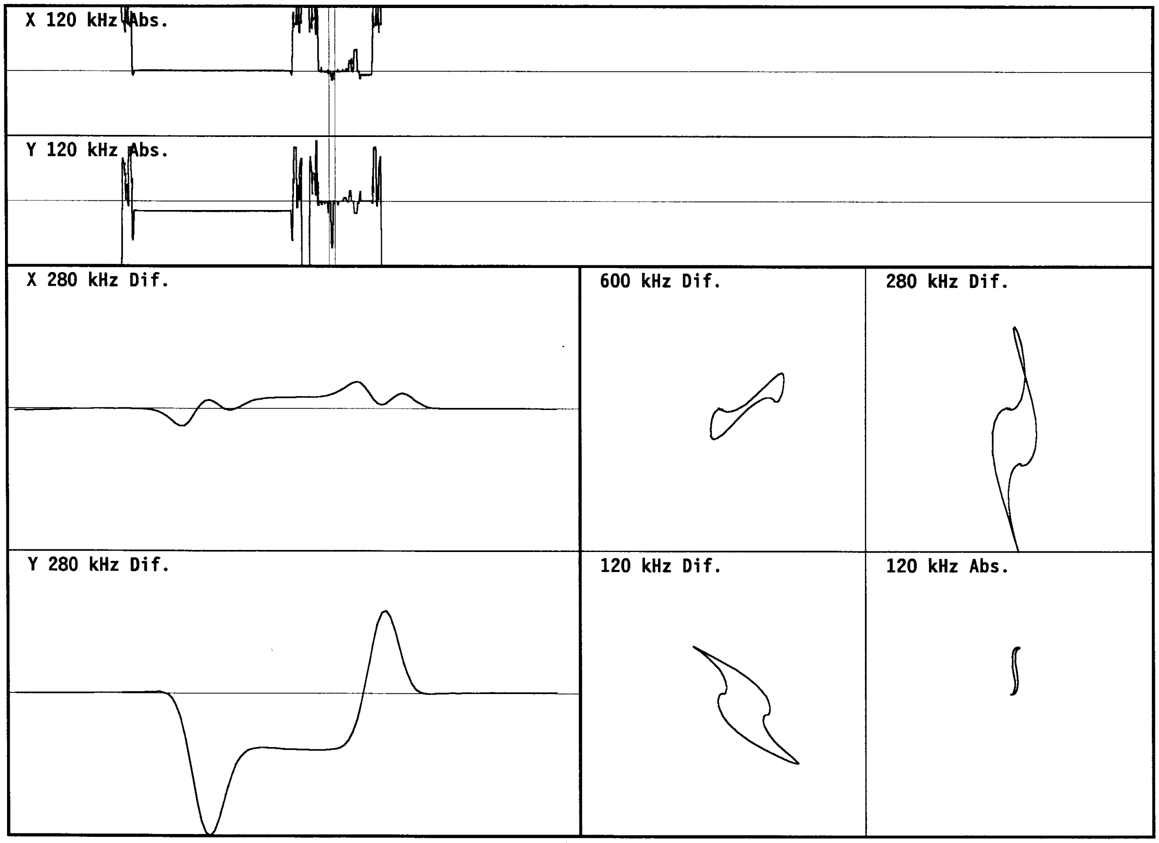

Figure 6-20
Unacceptable recording with very high dissymmetry of differential signals

The recording in Figure 6-20 shows a wrong wiring of the probe coils. This recording is not acceptable as the resulting distorsion of signals in differential mode, at all frequencies, will make impossible :

- A correct calibration if this is a calibration standard recording,
- Any comparison with previous recordings for signal evolution, if it is a SG tube recording.

6.14 Probe Centering System

An ideal centering system is characterized by no measurement dispersion as defined in Section 5.

Dispersion due to the probe centering, calculated using the method described in Section 5, must be less than or equal to 15% of the average signal amplitude.

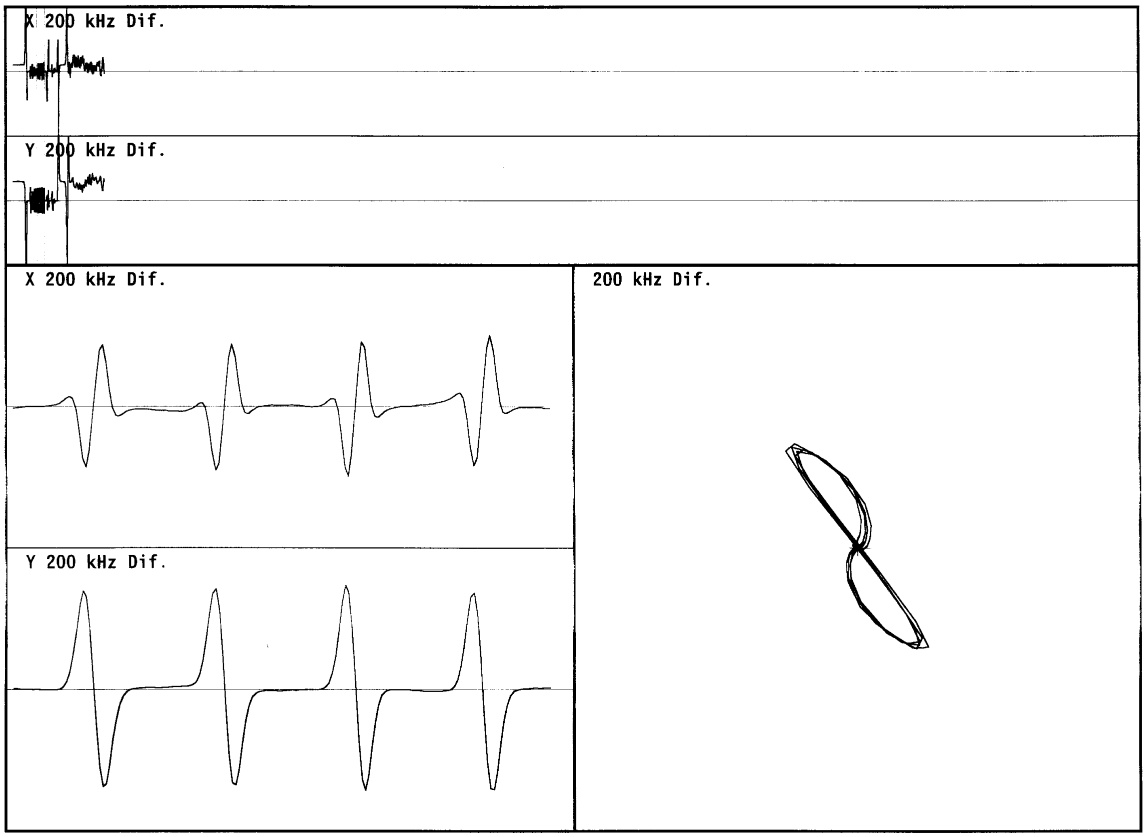

Figure 6-21
Acceptable recording with measurement dispersion < 15%

Figure 6-21, shows the recording obtained with a probe with an efficient centering system.

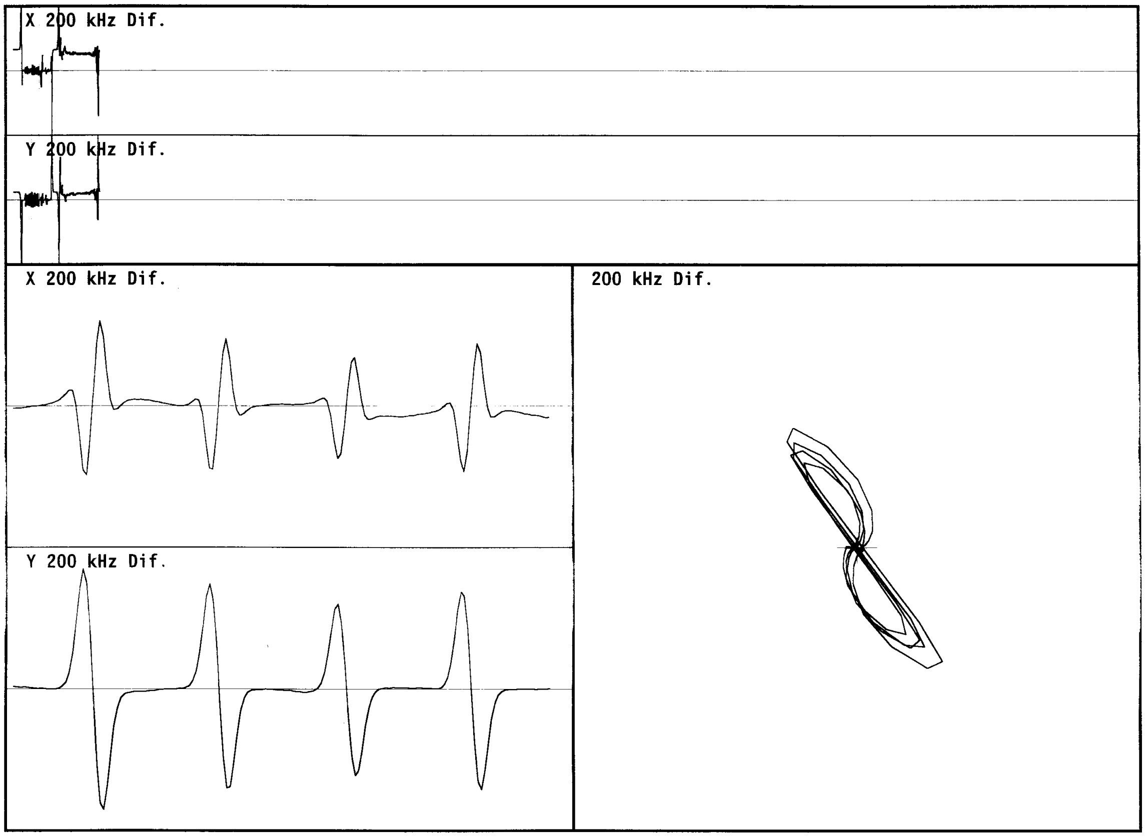

Figure 6-22
Unacceptable recording with dispersion

The signals on the recording in Figure 6-22 show a large dispersion in amplitude. This recording is not acceptable as signals in the differential mode are stongly influenced by the position of the coils with respect to the reference defect ; the centering system is not maintaining proper probe alignment. Any comparison with other recordings of the same tube is therefore impossible.

For all the measurements described in Sections 6.15 through 6.20, a population of 200 recordings, taken at random from different industry sources, have been analyzed in terms of the parameter being considered. Classical statistical calculations (average, standard deviation, etc.) were made on the results from the industry data.

6.15 Imbalance of Probe

Generally, bobbin coil probes do not show any variation of the balancing point in the differential mode. The acceptance criterion is selected to ensure that the two coils of the probe are equal and allow a correct differential measurement.

The acceptance criterion is derived from statistical measurements and expressed as a percentage of the eddy current instrument dynamic range.

Table 6-1
Statistical measurement of the probe imbalance[2]

Mode	Average value	Standard deviation	Minimum value	Maximum value	Average - 2 σ	Proposed threshold
Differential	1.5 V	1.5 V	0.0 V	7.0 V	4.6 V or 11.5%	**5 V or 12.5%**

Based on a statistical evaluation of industry data, shown in Table 6-1, probe imbalance should be less than or equal to 12.5% of the maximum dynamic range for each frequency in the differential mode.

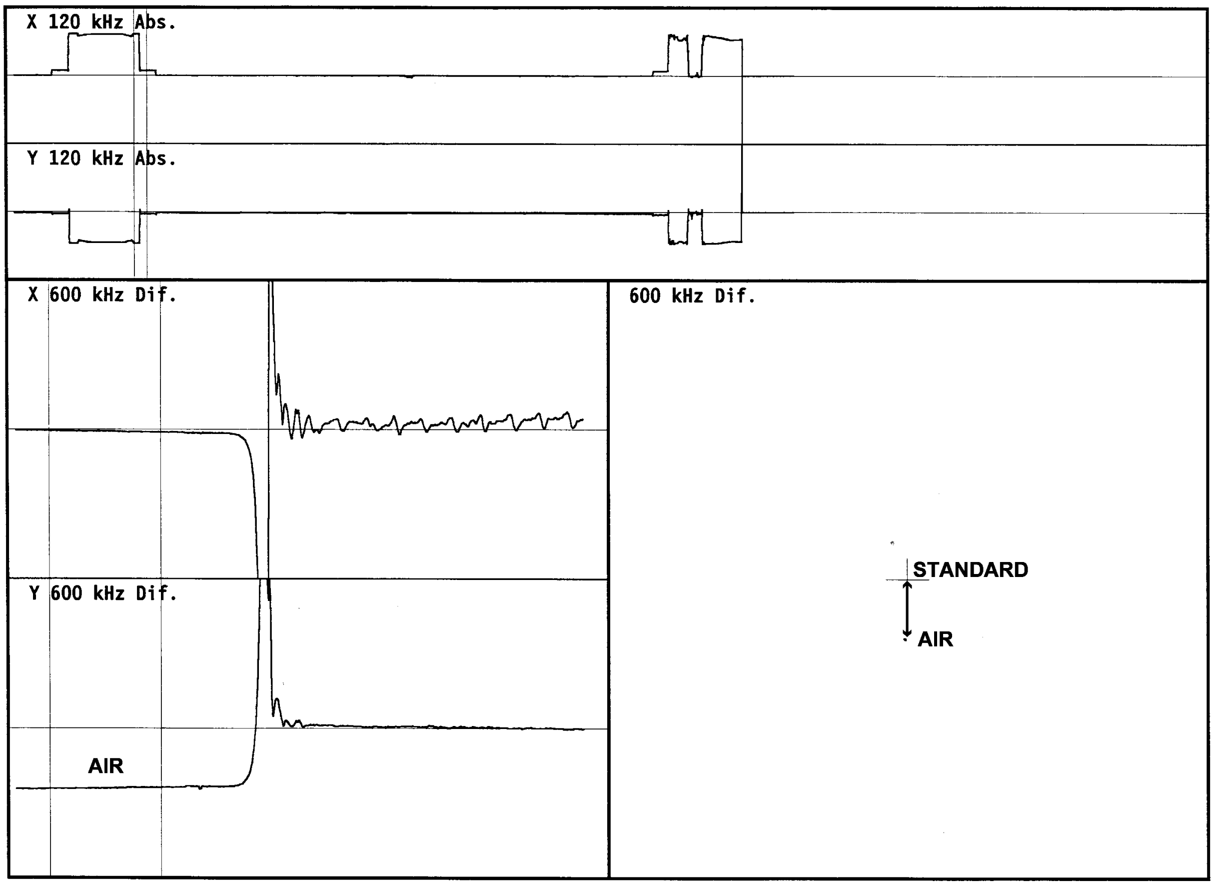

Figure 6-23
Unacceptable recording with probe imbalance

The recording in Figure 6-23 shows imbalance of the probe coils. This recording is not acceptable as some signals in differential mode such as roll transition signals or inner diameter

[2] Measurements were carried out on a population of 200 samples (50 recordings of a calibration standard). Results are given for an instrument with a ± 40 volt dynamic range.

variation signals are more or less distorted by the imbalance, making comparison with other recordings of the same tube no longer possible.

6.16 Offset

After balancing, the imbalance (or offset) of the measuring system in differential mode is, theoretically, very low, or even null. The acceptance criterion is selected to guarantee a dynamic range which is sufficient to avoid saturation of high-amplitude signals due, for example, to expansion transitions or to geometrical variations in low row U-bends.

The acceptance criterion is derived from statistical measurements and expressed as a percentage of the eddy current instrument dynamics.

Table 6-2
Statistical measurement of the offset[3]

Mode	Average value	Standard deviation	Minimum value	Maximum value	Average - 2 σ	Proposed threshold
Differential	2.64 V	4.1 V	0.05 V	17.38 V	10.91 V or 27.3%	**10 V or 25%**
Absolute	4.52 V	4.8 V	0.08 V	24.26 V	14.22 V or 35.6%	**15 V or 37.5%**

Based on a statistical evaluation of industry data, shown in Table 6-2, measuring system imbalance should be less than or equal to 25% of the maximum dynamic range for each frequency, in the differential mode. It should be less than or equal to 37.5% of the dynamic range for each frequency, in the absolute mode.

[3] Measurements were carried out on a population of 200 samples (50 recordings of a calibration standard). Results are given for an instrument with a ± 40 volt dynamic range.

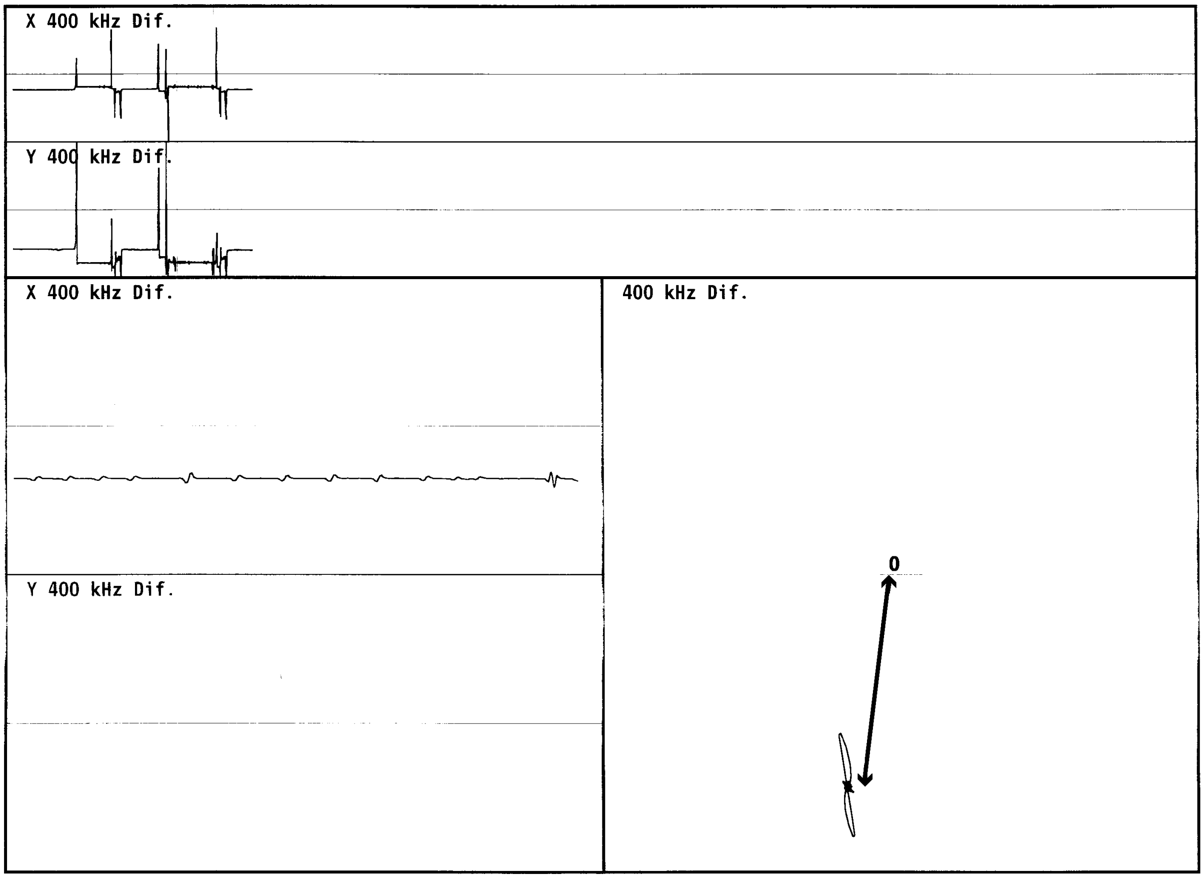

Figure 6-24
Unacceptable recording with offset

The recording in Figure 6-24 shows a strong offset, greater than 10 volts. This recording is not acceptable as some signals such as roll transition signals or inner diameter variation signals could consequently be saturated.

6.17 Offset Variation

An ideal measurement system would show no drift, as observed in Figure 6-25.

The acceptance criterion is set to a value equal to 5% of the dynamic range of the measurement system.

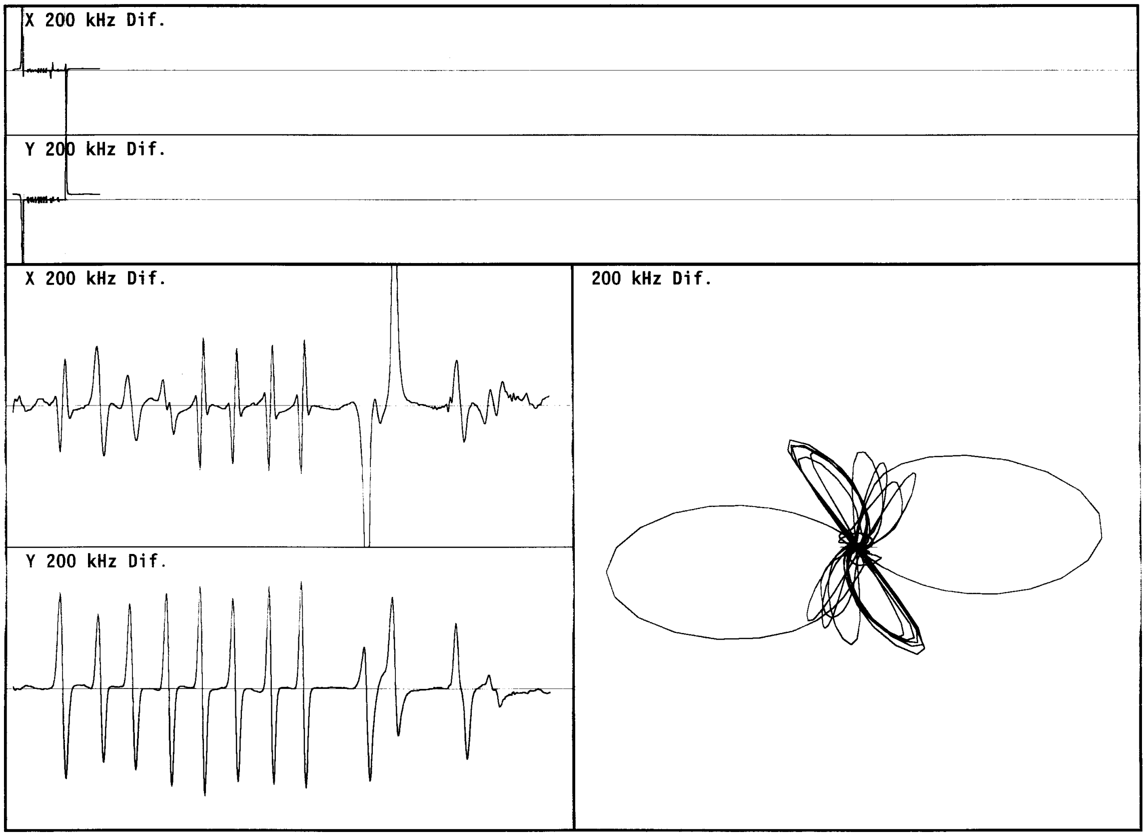

Figure 6-25
Acceptable recording without offset variation

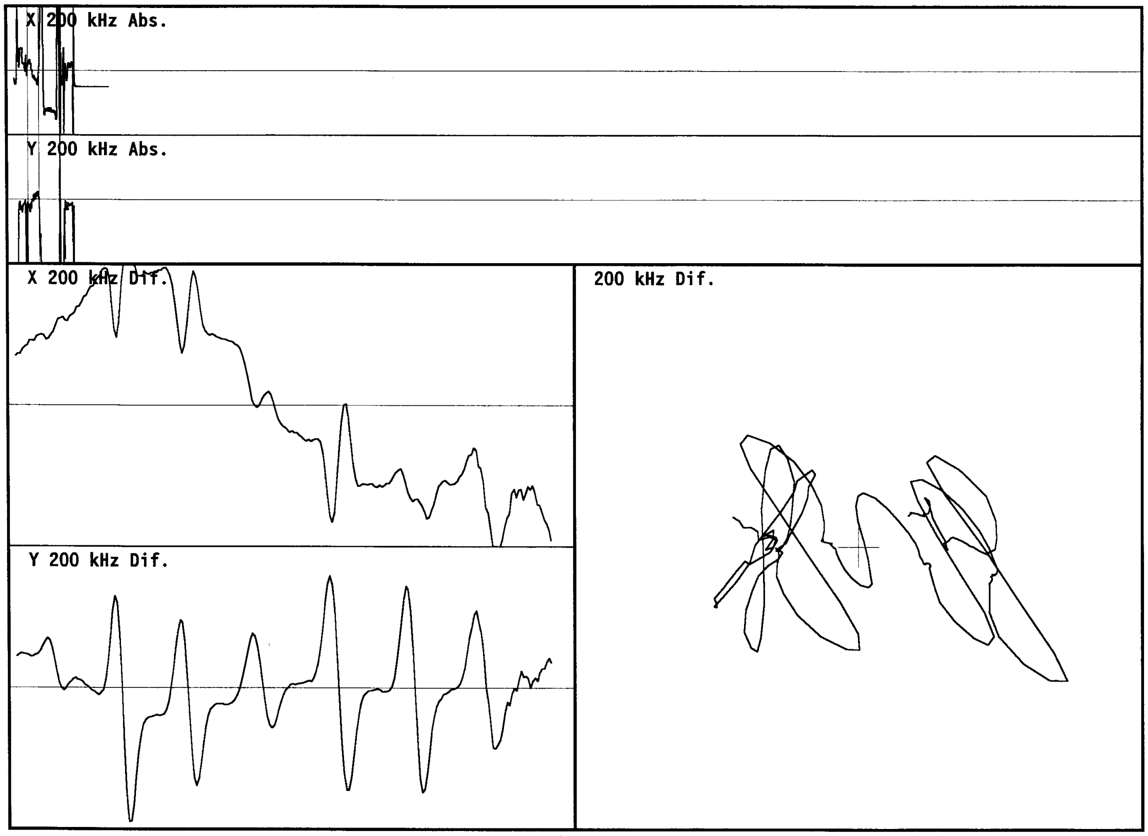

Figure 6-26
Unacceptable recording with offset variation

Figure 6-26 shows a calibration standard recording with an offset constantly varying from the beginning to the end of the recording; Reference signals severely distorted by the offset variation cannot be used for amplitude and phase measurements.

6.18 System Dynamics

Digitization of signals by sampling over time leads to deterioration.

The error due to signal digitization (E_d) is a function of the number of bits describing the signal, according to the following formula: $E_d = \frac{1}{2^{(n-1)}}$

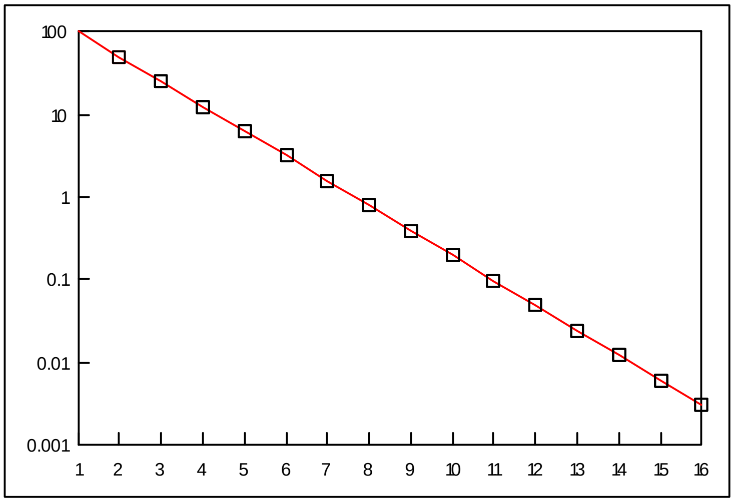

Figure 6-27
Measurement error (percentage) as a function of the number of digitization bits

The measurement error decreases exponentially as the number of digitization bits used to digitize the signal increases. From the curve in Figure 6-27, it can be seen that in order to obtain an error smaller than 2%, the signal shall be digitized on at least 7 bits. The amplitude of the reference signal used for calibration shall be close enough to the normalized value to avoid introducing a systematic measurement error on all signals after calibration. The gain adjustement carried out automatically at this stage should be as small as possible.

The acceptance criterion is derived from statistical measurements and stated in dB.

Table 6-3
Statistical measurement of the system dynamics[4]

Mode	Average value	Standard deviation	Minimum value	Maximum value	Average - 2 σ	Proposed threshold
Differential	8.3 dB	4.1 dB	-0.9 dB	26.9 dB	16.6 dB	**12 dB**
Absolute	1.0 dB	3.1 dB	-4.0 dB	15.3 dB	7.2 dB	**12 dB**

Based on a statistical evaluation of industry data, shown in Table 6-3, gain adjustment on calibration should be less than or equal to +12 dB for all the test frequencies in the absolute and differential mode.

6.19 Signal Dropout

A variation in the signal baseline sometimes corresponds to a momentary loss of measurement points. This absence of data points, even over a short distance, can conceal degradation.

[4] Measurements were carried out on a population of 200 samples (50 recordings of a calibration standard).

Acceptance Criteria

The acceptance criterion is set to a value less than or equal to 5% of the maximum dynamic range of the measurement system.

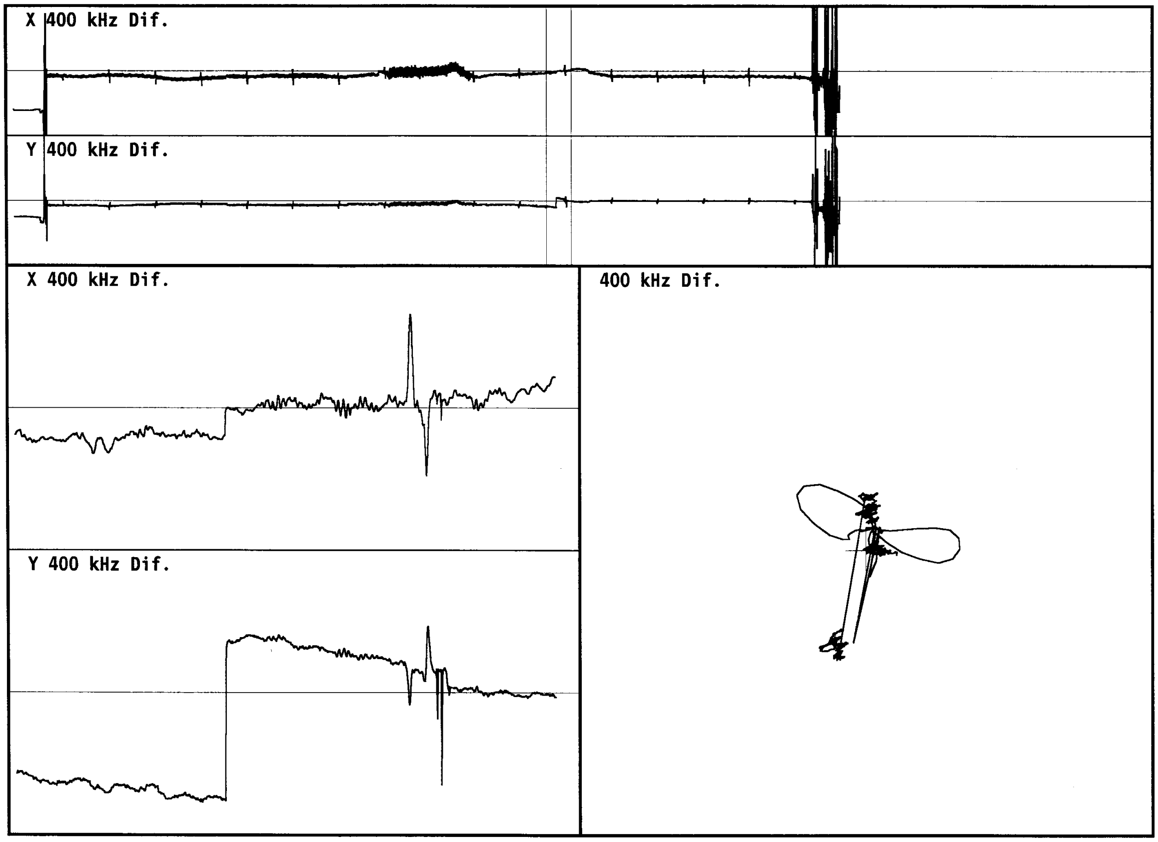

Figure 6-28
Unacceptable recording with signal dropout

The recording in Figure 6-28 shows a signal drop-out during the inspection of a SG tube. This recording is unacceptable since this drop-out :

- could conceal a loss of data including one or more indications,
- can distort the signal from a defect if it occurs simultaneously.

6.20 Signal-to-noise Ratio

Electronic Noise

Noise is a parasitic signal of variable amplitude which appears continuously throughout data acquisition. This noise should always be kept as low as possible because it reduces detection sensitivity when combined with signals of interest, and it changes the amplitude and the phase of the indication signal.

Complete elimination of noise in the eddy current data is not possible and it is more accurate to speak of noise reduction. Some methods, such as filtering or frequency mixes may be used for this purpose, but even then, it is always preferable to start with a low level of noise.

The acceptance criterion is derived from statistical measurements and stated in dB.

Table 6-4
Statistical measurement of the signal-to-noise ratio[5]

Mode	Average value	Standard deviation	Minimum value	Maximum value	Average - 2 σ	Proposed threshold
Differential	44.5 dB	5.9 dB	22.6 dB	57.4 dB	32.7 dB	**30 dB**
Absolute	38.1 dB	7.7 dB	14.3 dB	53.8 dB	22.7 dB	**20 dB**

Based on a statistical evaluation of industry data, shown in Table 6-4:

- Signal-to-noise ratio should be greater than or equal to 20 dB for each frequency in absolute mode.
- Signal-to-noise ratio should be greater than or equal to 30 dB for each frequency in differential mode.
- Signal-to-noise ratio should be greater than or equal to 10 dB for the low frequency used for landmark detection in absolute mode.
- Signal-to-noise ratio should be greater than or equal to 20 dB for the low frequency used for landmark detection in differential mode.

[5] Measurements were carried out on a population of 200 samples (50 recordings of a calibration standard).

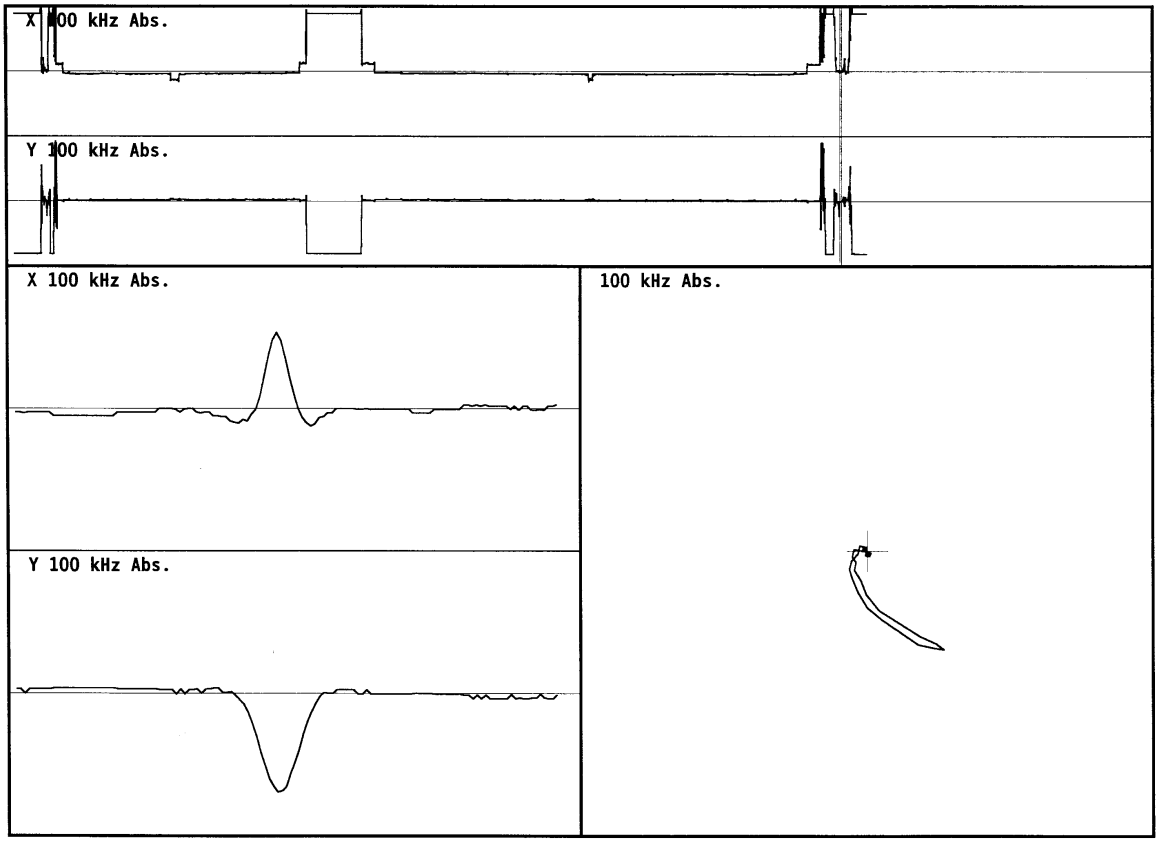

Figure 6-29
Acceptable recording without exceeding S/N ratio threshold value.

Figure 6-29 is an example of a recording with an absolute signal for which S/N ratio does not exceed the threshold value.

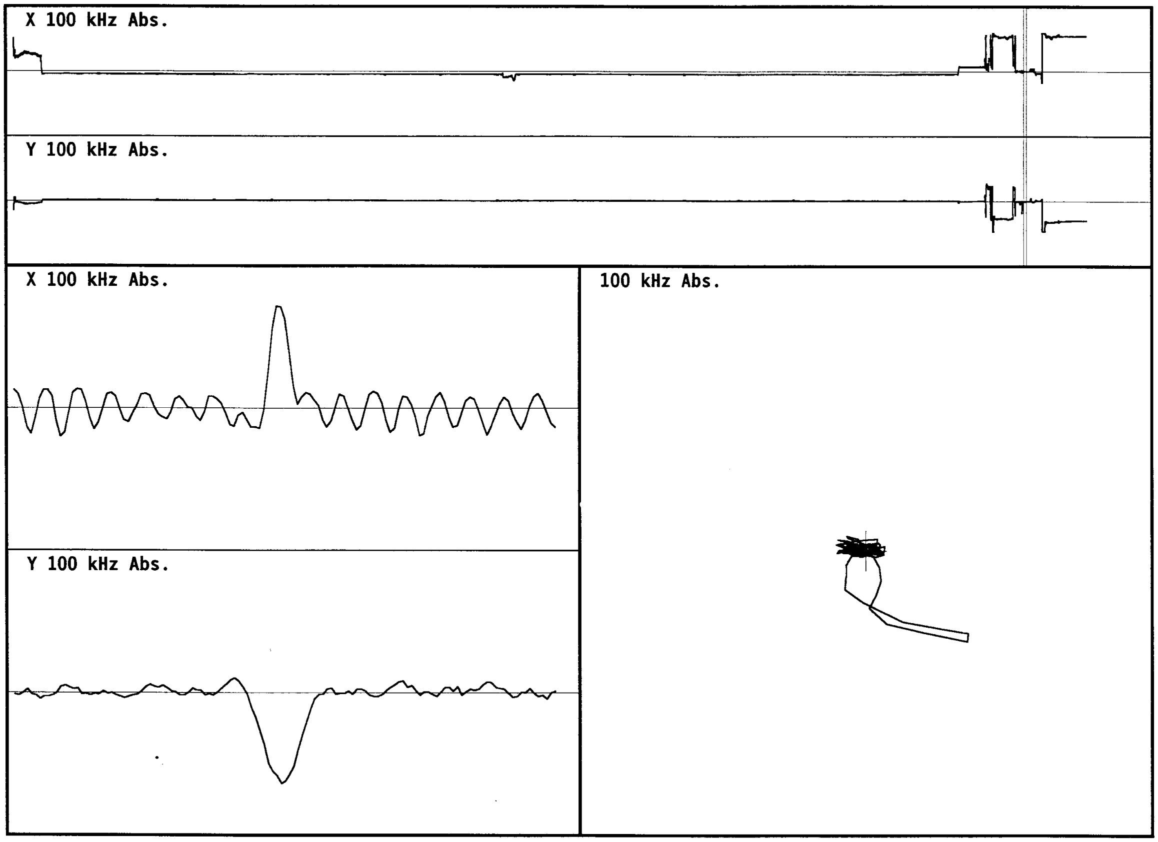

Figure 6-30
Unacceptable recording exceeding S/N ratio threshold value.

The recording in Figure 6-30 shows poor signal-to-noise ratio. This recording is not acceptable as the presence of high level noise :

- can conceal a defect signal having a small amplitude, (S/N < 6 dB),
- can distort signals and make amplitude and phase measurements inaccurate.

Spikes

Spikes (or parasitic noise) are detrimental to the analysis of signals if the ratio of the number of spikes over the certain length of acquired data is high. Therefore, the acceptance criterion is defined as a number of spikes per second of recording. It is not possible to set a value of threshold derived from theory ; only experience allows this value to be defined.

No measurement channel of the examined area or of the Quality Standard shall exhibit more than one spike per second of recording. In addition, spikes shall not appear simultaneously on several measurement channels.

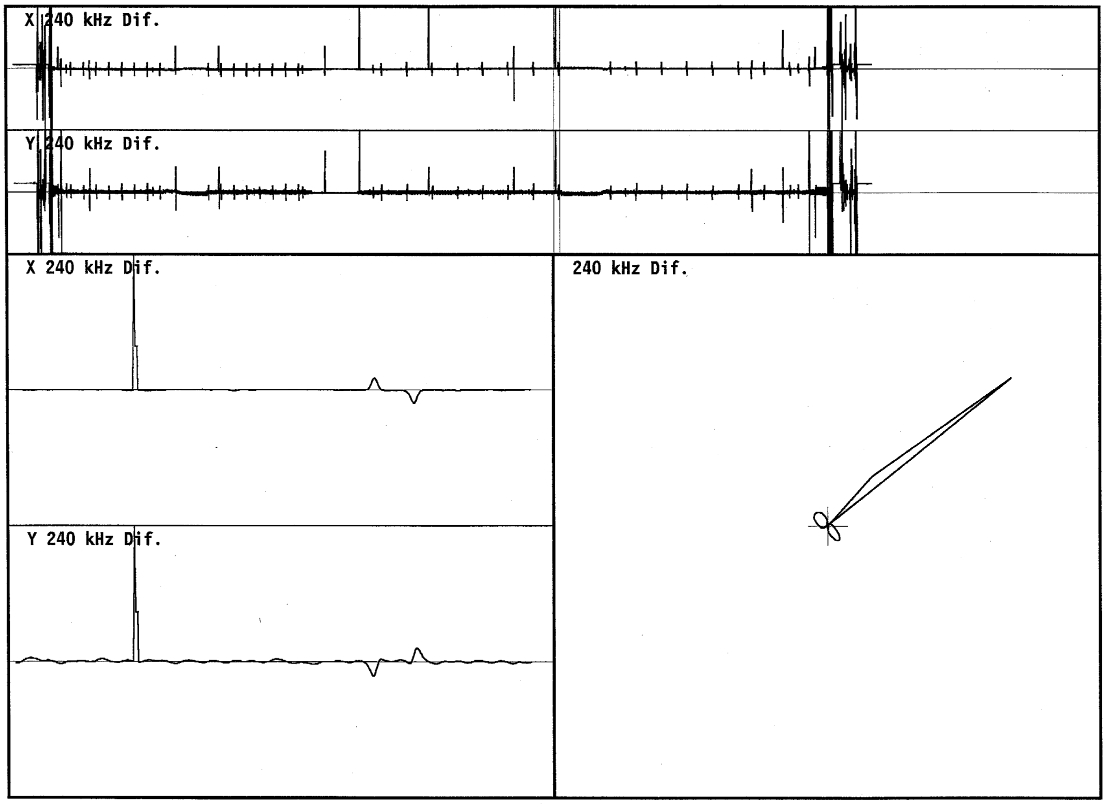

Figure 6-31
Acceptable recording with spikes

The recording in Figure 6-31 shows a few spikes. This recording is acceptable as the small number of spikes will still allow signal analysis to be performed.

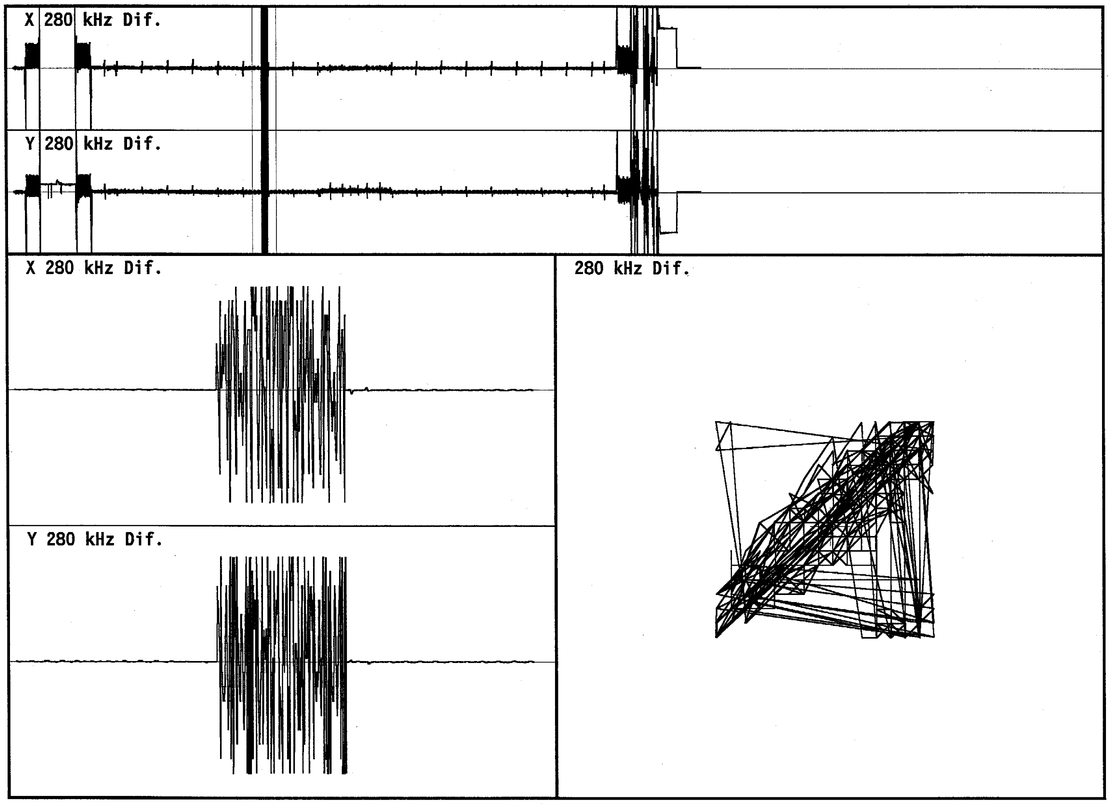

Figure 6-32
Unacceptable recording with spikes

The recording in Figure 6-32 shows numerous spikes concentrated in one zone of the tube being examined. This recording is not acceptable as the presence of spikes does not allow defect detection and can conceal one or more indications.

6.21 Review of Data Quality Acceptance Criteria

Table 6-5 summarizes the acceptance criteria related to each data quality parameter.

Table 6-5
Summary of quality parameter measurements and acceptance criteria

Quality Parameter	Acceptance Criteria
Tube identification	Correct site, unit, SG and tube coordinates
Extent tested – full length	2 tube/air transitions
Extent tested – partial length	1 tube/air transition
Presence of a calibration standard	>= 1 file *
	< 4 hours *
	2 cal. standard/air transitions
Presence of the Quality Standard	2 transitions
Loss of bits	No bit loss
Saturation	No saturation
Measurement on reference defects	No inversion of channels
Presence of eddy current signals	No channel loss
Digitization rate	>= 30 samples / inch *
Probe speed variation	± 10% of nominal speed
Probe flux	>= 95%
Symmetry of a differential signal	<= 20 %
Probe centering system	<= 15 %
Imbalance of probe	<= 12.5% of dynamic range

(*) PWR Steam Generator Examination Guidelines

Summary of quality parameter measurement and acceptance criteria (continued)

Quality Parameter	Acceptance Criteria
Offset in differential mode	<= 25% of dynamic range
Offset in absolute mode	<= 37.5% of dynamic range
Offset variation	<= 5% of dynamic range
Signal dropout	<= 5% of dynamic range
System dynamics in differential mode	<= + 12 dB
System dynamics in absolute mode	<= + 12 dB
Signal drop-out	<= 5% of dynamic range
Signal / noise ratio in differential mode	>= 30 dB (20dB for low frequency)
Signal / noise ratio in absolute mode	>= 20 dB (10 dB for low frequency)
Absence of parasitic noise	<= 1 spike / s and < 2 channels

7
INFLUENCE OF NON-QUALITY ON DATA ANALYSIS

This section of the report considers the extent to which examples of non quality may affect the detection of degradation on the basis of the following measurements:

- amplitude of the signal corresponding to degradation
- signal-to-noise ratio of the signal corresponding to degradation

Also considered is the extent to which examples of non quality may affect the characterization of degradation and the repeatability of the following measurements:

- amplitude of the signal corresponding to degradation
- phase of the signal corresponding to degradation
- size of degradation
- position of degradation in relation to the geometry of the tube

The following discussion summarizes data quality parameters according to their influence on detection and measurement, where measurement is divided into two areas :

- characterization (amplitude, phase, length) and,
- axial position of the signal of interest.

7.1 Quality Parameters Affecting Detection

Detection of degradation is based on sorting out signals of a given amplitude and phase and/or signals having a certain shape, while screening the data on different raw and/or process channels. Parameters affecting detection through amplitude/phase measurement and/or signal shape characterization are :

1. Incomplete acquisition - degradation location is not recorded
2. Saturation - degradation is hidden in a saturated zone or amplitude/phase/signal shape determination is incorrect due to saturation
3. Presence of spikes - same as saturation
4. Electronic noise - low amplitude signals submerged in noise; amplitude/phase/signal shape is modified

5. Loss of bits - same as electronic noise

6. Signal dropout - same as spikes with possible loss of information leading to incomplete acquisition

7. Absence of channel(s) – screening channel(s) not available

The problems listed above, if they occur, can cause degradation to go undetected.

7.2 Quality Parameters Affecting Characterization

Characterization of detected degradation consists in amplitude, phase, length and/or width measurement. Parameters affecting signal characterization are:

1. Saturation - both amplitude and phase measurements are incorrect if performed on saturated signals; excessive saturation may have an effect on detection.

2. Digitization rate – insufficient digitization rate leads to poor signal definition and uncertainties in measurement

3. Loss of bits - uncertainties in measurement

4. Probe speed variation – uncertainties in measurement

5. Excessive noise - uncertainties in measurement

6. System dynamics - uncertainties in measurement

7. Offset variation - uncertainties in measurement

7.3 Quality Parameters Affecting Location Measurements

Parameters affecting the ability to accurately locate signals of interest are:

1. Digitization rate – affecting positioning through incorrectly applied speed(s),

2. Probe speed variation – affecting positioning

7.4 Quality Parameters Affecting Repeatability

All quality parameters affecting detection and measurement of degradation also affect data repeatability from one acquisition to another during the same inspection or over several inspections.

Where the bobbin coil probe is only used for detection of degradation, the parameters to be considered are exclusively those which affect detection.

7.5 Review of the Effect of Quality Parameters

Certain quality parameters, as defined in this document, have no direct influence on the quality of eddy current signals themselves but do have an impact on the overall performance of an inspection. Table 7-1 summarizes the existence (√) of an effect on detection, then characterization and location of an indication.

Table 7-1
Influence of quality parameters on detection, characterization and location

Quality Parameter	Detection	Characterization	Location
Tube identification	No direct influence on detection, nor on measurement but highly important for the inspection, and particularly for data management		
Extent tested	√	√	√
Presence of a calibration standard	√	√	√
Presence of the quality standard	No direct influence; presence required to perform other verifications		
Digitization – loss of bits	√	√	No effect
Saturation	√	√	√
Measurement on reference defects	√	√	No effect
Presence of eddy current signals	√	√	√
Coils arrangement	√	√	√

Influence of quality parameters on detection, characterization and location (cont.)

Quality Parameter	**Detection**	**Characterization**	**Localization**
Digitization rate	No effect (except extreme cases)	√	√
Speed variation	No effect (except extreme cases)	√	√
Signal-to-noise ratio - electronic noise	√	√	No effect
Signal-to-noise ratio - parasitic noise	√	√	No effect
Offset	No effect (except saturation)	No effect (except saturation)	No effect
Offset variation	No effect (except saturation)	√	No effect
Signal dropout	√	No effect	No effect
System dynamics	No effect	√	No effect

8
QUALITY CHECK SPECIFICATIONS

8.1 Definition of Minimum Specifications

The effectiveness of a quality verification is closely linked to the choice of acceptance criteria. Loose criteria make the quality verification useless while too strict criteria disrupt the acquisition unnecessarily. Experience shows that the best approach is to apply quality verification gradually and to tighten the criteria in parallel with the improvement of data quality.

8.2 Definition of Quality Standard for On-Line Quality Check

In order to perform all of the data quality checks described in this document, a specific reference tube (Quality Standard) is required.

General Characteristics

The Quality Standard for performing a data quality check is always made from the same material, the same grade and with the same dimensions as the tubes to be examined.

The Quality Standard for performing a data quality check must not feature metallurgical degradation (noise or other signal interferences) so that there is no parasitic noise in the response from the reference defects.

To guarantee manufacturing quality and reproducibility, each Quality Standard used for the data quality check is subjected to both a dimensional characterization and an eddy current characterization.

Dimensional Characterization

The permissible mechanical tolerances relating to the dimensions of the quality standard are as follows:

- thickness: ± 0.12 mm (0.005 inch)
- external diameter: ± 0. 15 mm (0.006 inch)

The permissible mechanical tolerances relating to the dimensions of the reference defects are as follows:

- distance between defects: ± 1 mm (0.04 inch)
- angular location: ± 1°
- depth of defects: ± 0.01mm (0.0004 inch)
- width of defects (<1 inch): ± 0.01mm (0.0004 inch)
- width of wide defects (≥ 1 inch): ± 0.1mm (0.004 inch)

The recommended relative positions of artificial defects are :

- minimum distance between two consecutive defects: 2.5 cm (1.0 inch)
- minimum distance between the first (or last) defect and the closest end: 7.5 cm (3.0 inches)

Definition of Reference Defects

The results of the previous chapters allow the most appropriate in-line Quality Standard to be defined for implementing data quality check on-line with acquisition.

Table 8-1
Reference defects of the Quality Standard

Quality Check	Reference defect
Digitization rate	ID and OD defects / ID and calibration defect for differential channels
Measurement on reference defects	ID and OD defects
Presence of eddy current signals	ID and OD defects
Coils arrangement	Calibration defect for differential channels
Probe wiring	Calibration defect for differential channels
Symmetry of signal in differential mode	Calibration defect for differential channels
Centering of the probe	Centering defects
Imbalance of the probe in differential mode	Air area and sound area of calibration standard
Signal-to-noise ratio - electronic noise	Calibration defect for differential channels and sound area
Offset	2 sound areas
Offset variation	2 sound areas
System dynamics	Calibration defect for differential channels Calibration defect for absolute channels

As a minimum, the Quality Standard shall feature :

- one ID and one OD defect,
- one calibration defect for absolute channels,
- one calibration defect for differential channels,
- four defects 100% TW,
- two sound areas.

ID and OD artificial defects

ID and OD artificial defects are preferably grooves as the signal obtained is not influenced by probe centering.

The depth is small in order to obtain signals well discriminated in phase at all frequencies :

- ID : 10%
- OD : 20%

To allow easy manufacturing, the ID defect is located close to one extremity of the tube.

Calibration defect for absolute measurement

In order to minimize the error due to calibration, the signal used for amplitude normalization should be precisely measurable at all frequencies. The amplitude of the signal from four 20% TW flat bottom holes is always smaller than the signal from a groove of the same depth thus making the groove more appropriate for amplitude normalization of absolute channels.

The artificial defect for the absolute measurement is an OD groove , 30% deep and 0.5 inch wide. The signal obtained with a bobbin coil probe on this type of defect is not influenced by probe centering in the tube and absolute signals can be measured at all frequencies, with good accuracy.

Calibration defect for differential measurement

Reference [2] states that "…Voltage normalization shall be accomplished off the prime frequency on the four 20% through-wall (TW) holes, located on the ASME standard, and the voltage shall be normalized to 4 volts."

The 4x20% TW defects may not be the best defects for voltage normalization because :

- In order to bring the calibration error to a minimum, the signal used for normalizing amplitude should enable precise measurements at all frequencies. The amplitude of the 4x20% TW defect signal is always smaller than that of the 4x100%TW defect signal thus making the second one more appropriate for amplitude normalization of differential channels.
- When machining the 4x20%TW defect, two parameters must be controlled for reproducibility : the diameter of the holes and their depth. When machining a 4x100%TW defect, only one parameter must be controlled for reproducibility : the diameter of the holes. The scattering of the amplitude values of 4x20%TW defect signals is therefore higher than that of the 4x100% TW, [9].

The best suited calibration defect for the differential channels is a set of four 100% TW holes, 0.05 inch diameter, 90° apart on the same cross section of the tube.

Centering defects

Four artificial defects each separated by 90°, in four equally distant axial positions of the Quality Standard can be used for the verification of probe centering.

The basis for selecting 100% TW defects is explained in the previous subsection.

Sound Areas

The two sound areas are the two extremities of the reference tube.

They have sufficient length to avoid end effect signals and to allow noise and offset measurements to be made (sufficient number of measurement points).

Table 8-2 summarizes the features of the reference defects to be machined on the Quality Standard, a sketch of which is shown in Figure 8-1.

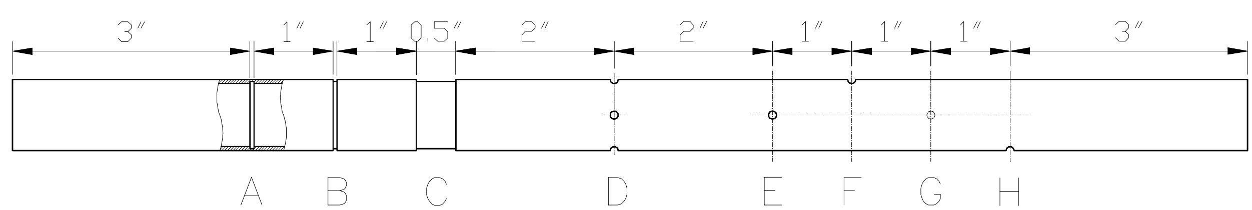

Figure 8-1
Quality Standard

Table 8-2
Reference defect review

Reference defect	Location	Type	Depth	Width
ID defect	A	ID groove	10%	0.05 inch
OD defect	B	OD groove	20%	0.05 inch
Calibration defect for absolute measurement	C	OD wide groove	30%	0.5 inch
Calibration defect for differential measurement	D	4 holes at 90° in the same section	100%	0.05 inch
Centering defects	E, F, G and H	4 holes at 90° in 4 sections	100%	0.05 inch
Sound Areas				2 x 1 inch

8.3 Limitations of the Specification

The definition of this Quality Standard is compared to that of the calibration standards currently used in the US, in order to evaluate the limitations of the data quality check when these calibration standards are used instead of the Quality Standard.

Tables 8-3and 8-4 include this comparison ; Table 8-5 specifies the limitations of the data quality check when using a calibration standard.

Table 8-3
Comparison of the Quality Standard with currently used calibration standards

Reference Defect	ID defect	OD defect	Cal. defect Absolute mode	Cal. Defect Differential Mode	4 Centering defects	Sound Areas
Quality Standard	10% ID groove 0.05 inch wide	20% OD groove, 0.05 inch wide	30% OD groove, ½ inch wide	4 x 100% holes, 0.05 inch diam.	4 x 100% holes , 0.05 inch diam.	2 x 1 inch wide
Zetec 950-0040	20% ID groove 1/16 inch wide	10% OD groove 1/16 inch wide	Not existing	4 x 20% holes, 0.187 inch diam.	Not existing	Not existing
Zetec dual guide tube standard	Not existing	4 x 20% holes, 0.187 inch diam.	Not existing	4 x 20% holes, 0.187 inch diam.	4 x 100% holes, 0.067 inch diam.	Not existing

Table 8-4
Comparison of the Quality Standard with the ASME calibration standard

Reference Defect	ID defect	OD defect	Cal. Defect Absolute mode	Cal. Defect Differential mode	4 Centering defects	Sound Areas
Quality Standard	10% ID groove , 0.05 inch wide	10% OD groove, 0.05 inch wide	30% OD groove ½ inch wide	4 x 100% holes, 0.05 inch diam.	4 x 100% holes, 0.05 inch diam.	2 x 1 inch wide
ASME standard	Not existing	4 x 20% holes, 0.187 inch diam.	Not existing	4 x 20% holes, 0.187 inch diam.	Not existing	Not existing

Table 8-5
Limitations of the specification when using ASME calibration standards

Quality Parameter	Quality Standard	Zetec 950-0045	Zetec 950-0040
Tube identification	√	√	√
Extent tested	√	√	√
Presence of a calibration standard	√	√	√
Presence of the quality standard	√	√	√
Saturation	√	√	√
Absence of parasitic noise	√	√	√
Loss of bits	√	√	√
Measurement on reference defects	√	Not possible	√
Presence of eddy current signals	√	Not possible	√
Digitization rate	√	√	√
Probe speed variation	√	√	√
Probe flux	√	√	√
Symmetry of a differential signal	√	√	√
Probe centering	√	Not possible	Not possible
Imbalance of probe	√	√	√
Offset	√	√ *	√ *
Offset variation	√	√ *	√ *
Signal dropout	√	√	√
System dynamics	√	√ **	√ **
Signal / noise ratio	√	√ *	√ *
Total : 20 Tests	20	13	15

(*) Sound areas are replaced by two shorter areas on the calibration standard
(**) Only in differential mode.

9
IMPLEMENTATION OF ON-LINE QUALITY CHECK

Implementing an on-line data quality check is technically feasible but modifications need to be made on both the equipment and the inspection procedures.

9.1 Recommendations Related to Test Equipment

Calibration Standards

Implementation of this quality specification requires no changes to the calibration standards typically used but requires that an additional standard, i.e. Quality Standard, be used.

Probe

Design

This data quality specification requires no changes to the probe design.

Post fabrication test

In order to guarantee quality and reproducibility of fabrication, each probe shall undergo a post fabrication test including an eddy current test with more stringent acceptance criteria than the tests made on site.

Probe Extension Cable

This data quality specification requires no changes to the probe extension cables typically used.

Probe Pusher

This data quality specification requires no changes to the probe pushers typically used.

Probe Manipulator

This data quality specification requires no changes to the probe manipulators typically used.

Eddy Current Instrument

This quality specification requires no changes to the eddy current instrument typically used.

9.2 Recommendations Related to Procedures and Operating Conditions

Examination Technique Specification Sheet

As part of the performance of an on-line data quality check of acquired signals, the list of quality checks and the corresponding acceptance criteria should be included in the ETSS or the data acquisition procedure.

Acquisition Cycle

This data quality specification requires that the signals from the Quality Standard be recorded together with those from each examined tube in the same acquisition cycle.

For each examined tube, the recording shall include as a minimum :

- the whole tube length (or part of it, in the case of small radius U-bends),
- an intermediate zone, 100 mm (4 inches) long, (air, guide tube or conduit),
- the Quality Standard,
- an intermediate zone, 100 mm (4 inches) long, (conduit).

Data is recorded at the nominal speed defined by the ETSS or the data acquisition procedure.

Eddy Current Instrument Parameters

This data quality specification requires that the eddy current instrument be balanced after each probe replacement or each new calibration standard run.

The eddy current instrument shall allow for injection levels and gains to be adjusted so that they produce signals with amplitudes close to the normalization values.

Probe Speed

This data quality specification requires no changes in the planned probe speed.

Digitization Rate

Where the bobbin probe is used to detect degradation, the minimum digitization rate shall be 30 data points per inch.

Where the bobbin probe is used for detection and characterization of degradation, the minimum digitization rate shall be 30 data points per inch (if the measuring software features a function for measuring signals by extrapolation) or 50 data points per inch in all other cases.

10
REFERENCES

1. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section V, 1989, Appendix I and Section XI 1992, Appendix IV.

2. PWR Steam Generator Examination Guidelines, EPRI TR-107569, Revision 5 : Volume 1, September 1997

3. Steam Generator Automated Eddy Current Data Analysis. A Benchmarking Study, EPRI Report TR-111463

4. The Effects of Digitization Rates on The Analysis of Eddy Current Signals, 7th EPRI Steam Generator NDE Workshop, 1988.

5. French Methodology of Steam Generator Tubing Inspection, IAEA Specialists Meeting on Steam Generator Problems and Replacement, Madrid 1993.

6. Current Performance in The Eddy of Steam Generator Tube Inspections, 13th EPRI Steam Generator NDE Workshop, La Jolla, CA 1994.

7. Effective Management and Quality Control of Multiple Remote Data Analysis Locations, 16th EPRI Steam Generator NDE Workshop, Palm Beach Shores 1997.

8. QA Surveillance of SG Eddy Current Examinations, 17th EPRI Steam Generator NDE Workshop, Breckenridge 1998.

9. Influence of Calibration Procedure in Test Results, 17th EPRI Steam Generator NDE Workshop, Breckenridge 1998.

10. Acquisition Solutions, 18th EPRI Steam Generator NDE Workshop, Palm Beach 1999.

A
MEASUREMENT METHODS

Method for the Subdivision of Recordings

This method consists of subdividing the eddy current data recording into different areas which include:

- two main areas : the inspection area and the Quality Standard area,
- secondary areas, which correspond to the probe being in the air or to the probe passing into a conduit.

Processing of the eddy current data for each tube/Quality Standard produces either air/tube or tube /air transitions as follows:

- 3 transitions, if a partial length of the tube and Quality Standard is being recorded,
- 4 transitions if the complete length of the tube and Quality Standard is being recorded,

Processing is divided into three principal phases :

- calculation of the dividing threshold,
- scanning for transitions,
- removal of unwanted transitions.

Calculation of the dividing threshold

The dividing threshold is the modulus value of the raw signals on the low frequency in the absolute mode, allowing differentiation between the measuring points in the tube and those in the air.

X and Y being the coordinates of a point in the impedance plane display, this threshold depends on:

- average of measurements X_{air} in the air
- average of measurements Y_{air} in the air
- average of measurements X_{tube} in the tube
- average of measurements Y_{tube} in the tube

The average measurements are not calculated from all the measurements in the tube and in the air, but from a given number of successive measuring points.

The calculation is subdivided into four operations:

- selection of the lowest test frequency in absolute mode,
- calculation of the maximum amplitude from balancing points corresponding to the air area
- calculation of the minimum amplitude from balancing points corresponding to the tube area
- calculation of the dividing threshold corresponding to the average between the two amplitudes mentioned above

Calculation of averages for the air

The object is to find, among a certain number of positions in the sector, the one for which the average of the signal amplitudes is at its maximum.

The sector being scanned is determined using the following two parameters.

- the line of the first measuring point (or position of the sector),
- the number of measuring points to be measured (or width of the sector).

The width of the sector being scanned is approximately 250 measuring points.

The first 250 measuring points are not included in the areas scanned to avoid measuring of parasitic noise.

Scanning is carried out at intervals of approximately 8000 measuring points.

The following calculations are performed for each sector :

- calculation of the averages M_{xa} for X_{air} and M_{ya} for Y_{air}
- calculation of the modulus of averages $M_{air} = \sqrt{M_{xa}^2 + M_{ya}^2}$

The reference sector selected for the calculation of the threshold is the one whose modulus M_a is at maximum.

The *Mxa* and *Mya* averages therefore act as the reference for the threshold calculation.

If the value of the maximum modulus is less than 4 volts then the recording is incomplete or partial and the search for the maximum modulus is continued to the end of the recording.

Calculation of averages for the tube

The positions of sectors and the calculations are the same as for the “air”.

$$M_{tube} = \sqrt{M_{xt}^2 + M_{yt}^2}$$

The aim of the operation is to obtain a minimum modulus, (no longer a maximum one).

Calculation of the threshold

The dividing threshold (Sd) is calculated using the formula :

$$S_d = \frac{\sqrt{(M_{xa} - M_{xt})^2 + (M_{ya} - M_{yt})^2}}{2}$$

where, X and Y being the coordinates of a point in the impedance plane display:

Mxa = average of the measurements of X in the air,

Mya = average of the measurements of Y in the air,

Mxt = average of the measurements of X in the tube,

Myt = average of the measurements of Y in the tube.

Scanning for transitions

The operation consists of determining the measuring points for which the signal amplitude becomes higher or lower than the dividing threshold which was previously calculated. These particular measuring points are called transitions.

Scanning for transitions is performed every four measurement points, by calculating an average over three consecutive points. Scanning starts at the position of the sector corresponding to the air, which has been determined previously.

For each trio of measuring points, the following is calculated:

- calculation of averages M_x in X(t) and M_y in Y(t)
- calculation of the modulus of averages $M_o = \sqrt{M_x^2 + M_y^2}$

The comparison of modulus M with the dividing threshold allows the air/tube and tube/air transitions to be determined.

Removal of unwanted transitions

The object of this operation is to make the distinction between actual dividing transitions and those corresponding to parasitic noise signals and to eliminate those which do not correspond to actual transitions.

The operation is based on the measurement of the distance between two consecutive transitions, knowing that:

- two successive actual transitions are at least 800 measuring points apart,
- there are only 3 actual transitions for partial length recording,
- there are only 4 actual transitions for full length recording.

If the distance between two transitions is less than 800 points, then the two transitions are eliminated.

If the number of transitions is less than 3, then a part of the recording is missing.

Principle of the Calibration

The purpose of calibration is to calculate the standardization coefficients which will be applied to the values of amplitude and phase of unprocessed signals, in order to calibrate them.

The calculation is based on a comparison between theoretical and measured values.

Measuring is performed on the following defects of the Quality Standard :

- the 100% through wall defect for the differential mode,
- the wide external groove for the absolute mode.

The processing sequence will :

- determine the position of the wide groove signal, at the lowest frequency in absolute mode,
- calculate the position of the through wall defect signal,
- measure the wide groove signal in the absolute mode,
- measure the through wall defect signal in the differential mode,
- calculate standardization coefficients,
- calibrate the complete recording.

Since calibration is based on the measurements of the Quality Standard defect signals, their position in the recording must first be determined.

The low frequency recording in the absolute mode is scanned for the detection of the groove signal.

Once the position of the groove signal is known, the position of the through wall defect signal can be derived.

Position of defect signals on the Quality Standard recording

Scanning for wide defect signals

The scanning area is defined by the dividing air/tube and tube/air transitions corresponding to the Quality Standard. Parasitic noise at the beginning and the end of this portion of recording is not taken into account.

This operation identifies the signals corresponding to the most significant calibration defects, such as grooves, plates and dimensional variations.

The recording is scanned and the modulus value of each low-frequency measuring point in the absolute mode is compared to a threshold. If the scan is not effective, or does not allow the identification of all necessary defect signals, the threshold is then decreased and scanning is repeated. This operation must be repeated until the required number of defect signals is found.

The signals found are not necessarily signals corresponding to the defects being searched for. There are also signals coming from parasitic noise and their characteristic feature is that they are very short. Successive signals, spaced by short time intervals (less that 10 measuring points), are eliminated.

When the scanning is completed, if the number of defects which were supposed to be found has not been reached, an error message is generated.

Locating the through wall defect

The physical distance between the wide groove and the through wall defect on the Quality Standard is known. Combining this distance with the digitization rate, the position of the through wall defect signal is derived from the groove signal position, by applying a shift which corresponds to the calculated number of data points.

Calculation of standardization coefficients

Two standardization coefficients are calculated for each frequency:

- the amplitude standardization coefficient (Ca),
- the phase standardization coefficient (Cp),

using the following formula:

$$Ca = \frac{At}{Am} \quad \text{and} \quad Cp = Pt - Pm$$

where:

At (volts) = normalized theoretical calibration amplitude,

Pt (degrees) = normalized theoretical calibration phase,

Am (volts) = amplitude of the raw measured signal,

Pm (degrees) = phase of the raw measured signal.

Measurement of the Amplitude and Phase of a Signal

Eddy current signal analysis relies very often on the measurement of the amplitude and the phase of signals. It consists in measuring the amplitude and phase of the vector linking two characteristic points of the signal, one of them being taken for origin. In the absolute mode,as shown in Figure A-1, the characteristic points for measuring the vector are the balancing point and the signal peak.

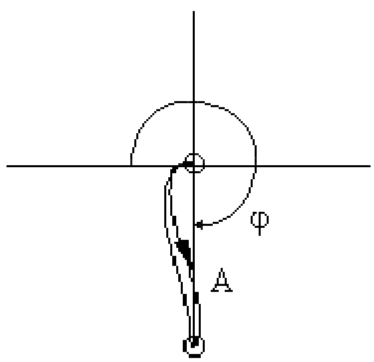

Figure A-1
Absolute signal measurement

In the differential mode, as shown in Figure A-2, the characteristic points for measuring the vector are the two extreme points of the signal.

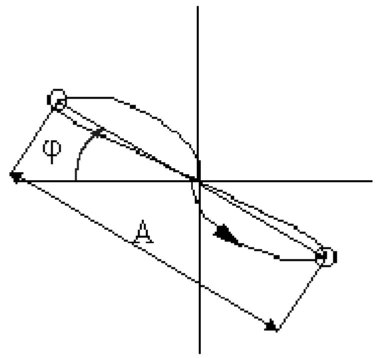

Figure A-2
Differential signal measurement

Using the coordinates of these two points in the impedance plane, the amplitude A and the phase φ are calculated by the formula:

$$A = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2} \text{ and } \varphi = \arctan\left[\frac{(X_1 - X_2)}{(Y_1 - Y_2)}\right]$$

Measurement of Noise Amplitude

Noise amplitude is measured using the following formula:

$$N = \sqrt{N_x^2 + N_y^2}$$

where:

Vertical noise: $N_y = \sqrt{\dfrac{\sum_{i=1}^{n}\left(Y_i - \overline{Y}\right)^2}{n}}$ with $\overline{Y} = \dfrac{\sum_{i=1}^{n} Y_i}{n}$

Horizontal noise: $N_x = \sqrt{\dfrac{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2}{n}}$ with $\overline{X} = \dfrac{\sum_{i=1}^{n} X_i}{n}$

N (volts) = Total noise (RMS[6]).

[6] Root mean square value.

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