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CHRISTIAN B. LARSEN
Vice President and
Chief Nuclear Officer

PROJ669

April 29, 2009

Document Control Desk
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: Request for Withholding of the Following Commercial Documents:

1015126 Development of a Process for Determining Examination Technique Equivalency

1018557 Development of Standardized Process for Determining Examination Technique Equivalency

To Whom It May Concern:

This is a request under 10 C.F.R. §2.390(a)(4) that the U.S. Nuclear Regulatory Commission ("NRC") withhold from public disclosure the information identified in the enclosed Affidavit consisting of the commercial information owned by Electric Power Research Institute, Inc. ("EPRI") identified above (the "Report"). Copies of the Report and the Affidavit in support of this request are enclosed.

EPRI desires to disclose the Report in confidence as a means of exchanging technical information with the NRC. The Report is not to be divulged to anyone outside of the NRC nor shall any copies be made of the Report provided herein. EPRI welcomes any discussions and/or questions relating to the information enclosed.

If you have any questions about the legal aspects of this request for withholding, please do not hesitate to contact me at (650) 855-2329. Questions on the content of the Report should be directed to Thomas Bipes of EPRI at (704)-595-2210.

Sincerely,

Together . . . Shaping the Future of Electricity

3420 Hillview Avenue, Palo Alto, CA 94304-1338 USA • 650.855.2329 • Fax 650.855.8759 • cblarsen@epri.com

D035
NRR

AFFIDAVIT

RE: Request for Withholding of the Following Commercial Document:

1015126 Development of a Process for Determining Examination Technique Equivalency

1018557 Development of Standardized Process for Determining Examination Technique Equivalency

I, CHRISTIAN B. LARSEN, being duly sworn, depose and state as follows:

I am a Vice President and the Chief Nuclear Officer of Electric Power Research Institute, Inc. whose principal office is located at 3420 Hillview Avenue, Palo Alto, California ("EPRI") and I have been specifically delegated responsibility for the above-listed Report that is sought under this Affidavit to be withheld (the "Report"). I am authorized to apply to the U.S. Nuclear Regulatory Commission ("NRC") for the withholding of the Report on behalf of EPRI.

EPRI requests that the Report be withheld from the public on the following bases:

Withholding Based Upon Privileged And Confidential Trade Secrets Or Commercial Or Financial Information:

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b. EPRI made a substantial economic investment to develop the Report and, by prohibiting public disclosure, EPRI derives an economic benefit in the form of fees charged for the sale of the Report. The Report is entitled to the protection of the United States copyright laws. If the Report was publicly available to consultants and/or other businesses providing services in the electric and/or nuclear power industry at no cost, these entities would be able to use the Report for their own commercial benefit and profit and without expending the substantial economic resources required of EPRI to develop the Report.

c. EPRI made a substantial investment of both money and employee hours over an extended period of time in the development of the Report. As a result of such effort and cost, both in terms of dollars spent and dedicated employee time, the Report is highly valuable to EPRI.

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I have read the foregoing and the matters stated herein are true and correct to the best of my knowledge, information and belief. I make this affidavit under penalty of perjury under the laws of the United States of America and under the laws of the State of California.

Executed at 3420 Hillview Avenue, Palo Alto, California being the premises and place of business of Electric Power Research Institute, Inc.

April 29, 2009

C. B. L

Christian B. Larsen

State of North Carolina)
County of Mecklenberg)

Subscribed and sworn to (or affirmed) before me on this 29th day of April, 2009, by Christian B. Larsen, proved to me on the basis of satisfactory evidence to be the person(s) who appeared before me.

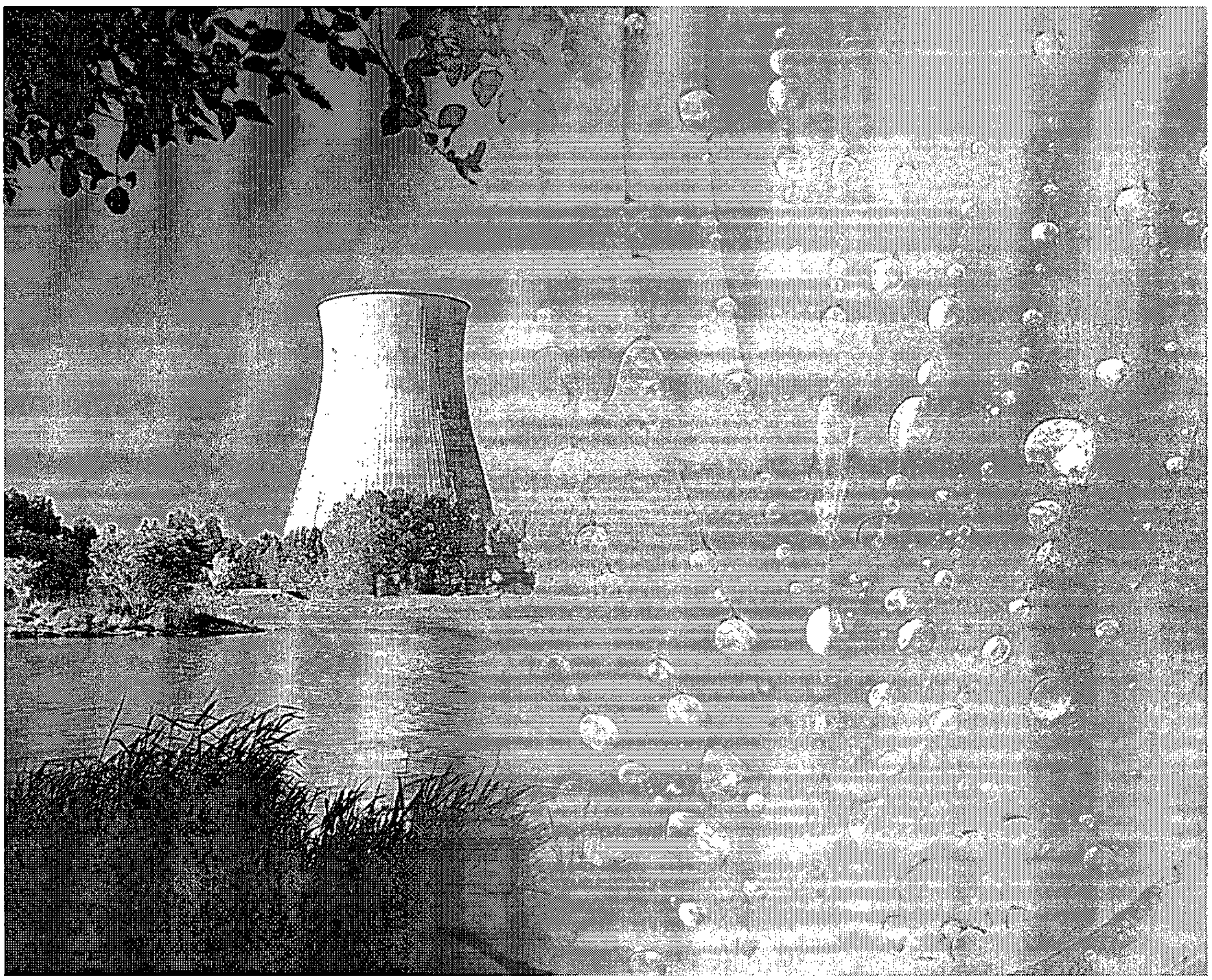
Signature Deborah D. Rouse, Notary (Seal)
My Commission Expires 4/2/2011

ELECTRIC POWER RESEARCH INSTITUTE

EPRI Non-Proprietary Version

Development of a Process for Determining Examination Technique Equivalency

1015126



Non-Proprietary Version

Development of a Process for Determining Examination Technique Equivalency

1015126

Technical Update, March 2008

EPRI Project Manager

J. Benson

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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Zetec Inc.

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

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8226 Bracken Place SE
Suite 100
Snoqualmie, WA 98065

Principal Investigator
S. Sullivan

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REPORT SUMMARY

Utilities use qualified techniques when performing eddy-current tests on nuclear power plant steam generator (SG) tubes. When components of the "qualified" system are changed, verification of equivalency to the originally qualified system must be performed. This report provides the initial results of EPRI's ongoing multiyear project that includes the development of a simplified, cost-effective method of determining eddy-current technique and substitute component equivalency.

Background

The EPRI PWR Steam Generator Examination Guidelines require an examination technique specification sheet (ETSS) to define essential variables for equipment, techniques, and analysis. Examination techniques with essential variables that vary within the ranges identified in the ETSS are considered equivalent.

In order to take advantage of technology advances in nondestructive examination (NDE) techniques and equipment, utilities must demonstrate technique or system component equivalency prior to implementation. The convention has been that each individual utility requires the inspection organization to develop the technical basis and assemble the required documentation that demonstrates technique or substitute component equivalency as part of their inspection services contract. The elaborate process currently performed to document equivalency has increased costs for the utilities involved. A simplified, cost-effective process for determination of examination technique equivalency could provide financial benefits to utilities.

Objectives

- To provide a consistent and cost-effective method to evaluate system performance, technique performance, and substitute component equivalency.
- To assemble equivalency documentation on various steam generator eddy-current inspection techniques.

Approach

Investigators developed a written plan for documenting equivalency for new examination techniques, where essential variables may be outside of the range of those defined in the originating ETSS. Measurement and acceptance of essential variables for the technique, individual system components, and analysis were to be considered in accordance with EPRI's Steam Generator Examination Guidelines.

Investigators developed a process where a utility engineer or a vendor organization could set up an identical examination system, as planned for field use, test the calibration standard flaw(s) or master sample, and immediately determine if the system is "equivalent" to currently qualified systems. System performance would be evaluated as a whole rather than trying to examine each individual system element. A method to standardize the evaluation of system performance was developed so as to achieve consistent eddy-current results.

In the final steps, investigators designed and produced a master set of flawed tube samples that could be used to perform examination technique equivalency checks. A procedure was developed for using the master samples to demonstrate examination technique equivalency.

Results

This report documents a method for demonstrating equivalency between EPRI-qualified eddy-current inspection techniques for steam generator tubes and similar inspection techniques with modified essential variables. The equivalency demonstration requires two components. One component is an engineering technical justification explaining why the changes in essential variables should not affect the performance of the technique in detecting and characterizing steam generator tube flaws. The other component is a practical demonstration showing that the modified techniques can generate signals from selected calibration tube flaws equivalent to those generated by the qualified techniques.

A master set of calibration tubes has been designed and built for demonstrating equivalency between qualified inspection techniques and new techniques with modified essential variables. A layout of an essential variables workbook table is also documented in this report. This workbook table has been developed as an aid in accounting for differences in essential variables between new proposed inspection techniques and qualified inspection techniques.

EPRI Perspective

The determination of steam generator eddy-current technique equivalency has been an involved and costly process. The development of a standardized and efficient process for determining eddy-current technique and substitute component equivalency should provide cost savings to utilities and should allow the determination of equivalency to be made in a much shorter period of time.

Keywords

Steam Generators
Essential Variables
Eddy-Current Inspection
Examination Technique Specification Sheet (ETSS)

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1 INTRODUCTION

As the industry has matured processes for improving inspection quality and efficiency have evolved. The EPRI PWR Steam Generator Examination Guidelines provides specific guidance for a steam generator inspection program. Included in these EPRI S/G Guidelines is the process of qualifying inspection techniques. Within each of the qualified techniques, essential variables have been identified with their established values and ranges. To vary any parameter of a qualified technique such as the substitution of a new component for an original, equivalency must be demonstrated. This document explains the process for demonstrating equivalency between an existing EPRI qualified eddy current inspection technique, and a new proposed inspection technique with modified essential variables. If equivalency cannot be demonstrated between a new proposed technique and an existing qualified technique, then the new technique requires full qualification in accordance with Appendix H of the EPRI PWR Steam Generator Examination Guidelines [1] if it is to be used in an inspection.

1.1 Purpose

The purpose of this document is to provide a framework for demonstrating equivalency of qualified techniques and a methodology for building an evidentiary report. This is not a substitute for site validation but rather a supporting document to demonstrate the equivalency of the technique components that will be used in the site validation.

1.2 Scope

Included in this document is an explanation of the process, specific requirements, and recommendations around how to produce a report which demonstrates technique equivalency. A technique is considered equivalent to a qualified technique if changes in essential variables do not degrade the performance indices of the technique in regard to detection and sizing capabilities.

2 PROCESS FOR DOCUMENTING TECHNIQUE EQUIVALENCE

The recommended process for documenting the equivalency between a new proposed eddy current steam generator tube inspection technique, and an existing qualified technique is depicted in the flow chart in Figure 2-1.

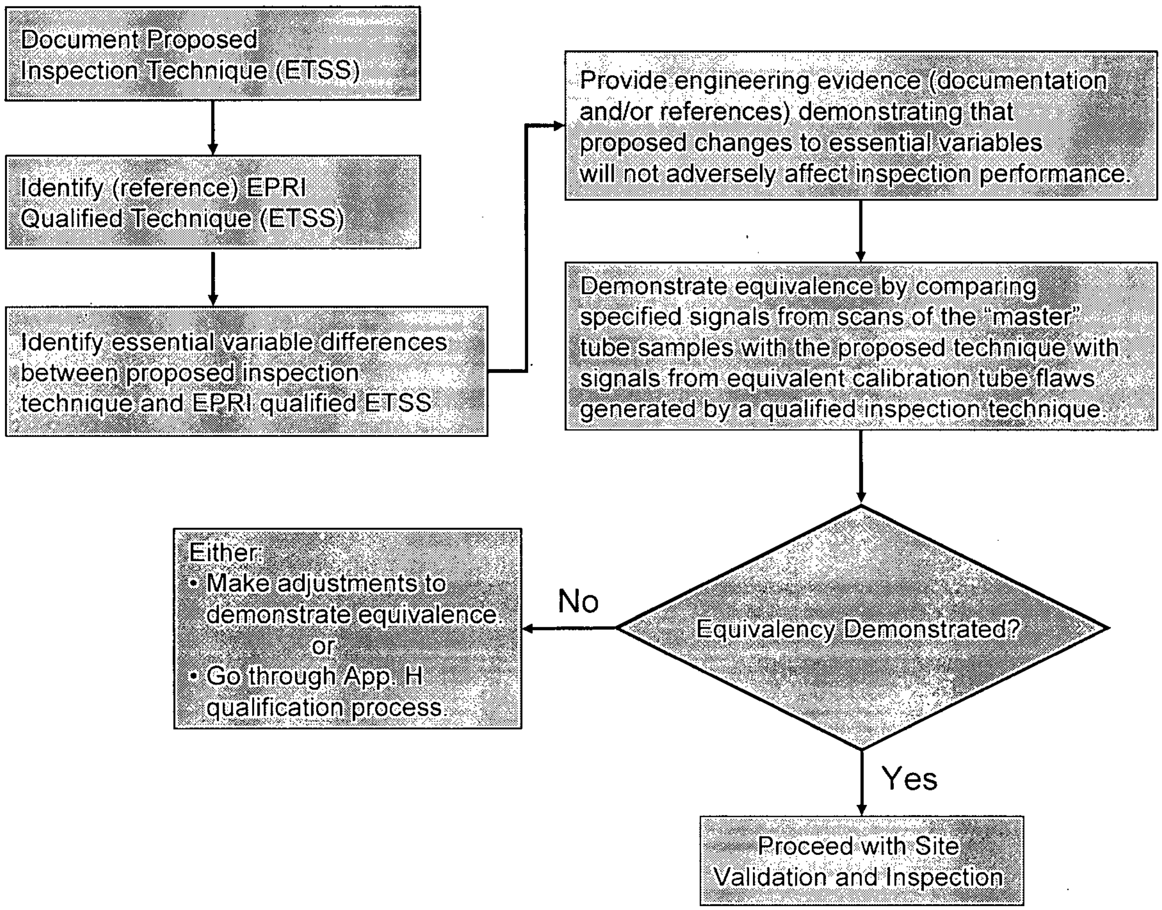

Figure 2-1
Flow Chart Diagram Showing How to Document Equivalency between a New Proposed Eddy Current Inspection Technique for Steam Generator Tubes and a Qualified Technique

2.1 Proposed ETSS

The proposed eddy current technique for steam generator tube inspection must be fully documented with examination technique specification sheets (ETSS). As a minimum, the information required to document the technique must be equivalent to the equipment, materials and procedural information documented in the qualified EPRI ETSS's.

2.2 Identify EPRI Qualified Techniques that are to be Demonstrated as Equivalent to the Proposed Eddy Current Testing Technique

The intended function of an eddy current testing technique is to be able to detect and characterize flaws in steam generator tubes with equivalent capability as techniques that have been qualified by the Appendix H process in the EPRI PWR Steam Generator Examination Guidelines [1].

2.3 Identify Differences in Essential Variables between the Proposed Technique and the Qualified Techniques

Differences in essential variables between those of the proposed ETSS and those of the qualified techniques must be identified and documented. Some common examples are listed below:

1. Different eddy current instrument.
2. Different acquisition software and/or analysis software.
3. Cable length compensated by cable capacitance, coil inductance, and/or drive voltage.
4. Minor probe coil changes (eg. minor change to inner diameter of a pancake coil).
5. Scan speed compensated by digitizing rate.
6. Tube wall thickness compensated by operating frequency.

2.4 Technical Justification

Any engineering arguments explaining why differences in essential variables will not adversely affect the proposed technique's ability to detect and characterize flaws equivalently to the qualified techniques must be documented.

For example, if it is desired to increase scanning speed of an eddy current probe, mathematical equations should be documented showing how an increase in digitizing rate will allow the technique with the faster probe to generate an equivalent amount of samples per inch as the technique that was originally qualified.

2.5 Performance Demonstration on Master Set of Calibration Tubes

If an eddy current technique is to be considered as equivalent to a qualified technique, it must be proven that it can generate equivalent calibration tube flaw signals. Repeatability errors are generally caused by tolerances in calibration tube dimensions, calibration flaw dimensions and eddy current equipment (probes, cables and instruments). Therefore, "equivalent" signals are not expected to be truly identical. Acceptance tolerances for signal comparisons have been determined by examining variances in calibration flaw signals from EPRI qualified techniques. Calibration tube flaw signals can either be obtained by setting up a qualified technique and scanning the appropriate calibration tubes, or by obtaining calibration flaw signals from archived data acquired with the qualified technique. Such data can be obtained from calibration tube scan files stored with EPRI's technique qualification records.

The performance demonstration for demonstrating equivalence requires two components. One component is a demonstration that the proposed system will generate a probe signal with equal or greater amplitude from a common flaw as would be produced by a probe from a qualified technique. This can often be accomplished by comparing a flaw signal from the proposed technique with a signal from an equivalent flaw from the qualified technique before the analysis setup is normalized.

The second required component of a performance demonstration is a comparison of signals from a comprehensive set of common calibration tube flaws after the signal setups have been appropriately normalized and phase adjusted.

Detailed documentation of the "master" set of calibration tubes used for demonstrating equivalence is in Section 3. More detailed explanations of how the signal comparisons should be done with specific acceptance tolerances are in Section 4.

3 MASTER SET OF CALIBRATION TUBES FOR PERFORMANCE DEMONSTRATION OF TECHNIQUE EQUIVALENCE

As a minimum, the EPRI PWR Steam Generator Examination Guidelines [1] require that bobbin probes used to scan steam generator tubes must be calibrated using ASME Section V Article 8 calibration standards. These guidelines also require that rotating probes and array probes should be calibrated with calibration tubes containing 0.375" long, 0.005" wide EDM notches of various depths from the outer diameter (OD) surface of the tube wall and the inner diameter (ID) surface of the tube wall. Because of this, archived data acquired with qualified eddy current techniques all contain signals from these calibration flaws. Therefore, as a minimum, a recommended "master" set of calibration tubes for demonstrating technique equivalence should contain ASME calibration standard flaws and the EDM notches required by the EPRI guidelines.

In addition to the calibration tube flaws required by the EPRI guidelines, it is also recommended to include a set of four 100% deep axial EDM notches at one axial location separated by 90 degrees from each-other along the tube circumference. This type of flaw is considered to be useful as scale-independent flaws for comparing bobbin probes built for scanning different diameter tubes. The conventional flat-bottom holes used in ASME tubes are scale dependent. The diameters of the flat bottom holes in ASME calibration tubes are fixed, independent of the diameter of the tube. Because of this, the relative size of these flat-bottom holes changes as the tube diameter changes. The circumferential extent of each flat bottom hole changes relative to the tube circumference as the tube diameter changes. For practical purposes, the 100% deep axial EDM notches are two-dimensional being significantly longer in the axial direction than the bobbin probe coils (and field spread) while occupying very little extent in the circumferential direction. The signal from these axial notches should be independent of the tube circumference and diameter.

When calibrating certain types of array probes such as X-Probes, the calibration tubes contain axially symmetric grooves. These grooves are often required to ensure that the various probe-coil units in the array probes are calibrated equivalently. When X-Probes were qualified for detecting cracks through the EPRI guidelines Appendix H process, signal amplitude was calibrated using a 20% deep axially symmetric groove. After the work in qualifying the X-Probe had been performed, it was recognized that the 20% deep groove was not deep enough to generate a consistent or repeatable enough signal for calibrating the probe. A deeper groove was needed. In most inspections that use X-Probes, signal amplitude is generally calibrated using a 30% deep groove rather than a 20% deep groove.

Detailed drawings of a recommended set of calibration tube samples with useful flaws for demonstrating equivalence between proposed eddy current inspection techniques and qualified techniques are shown in Figure 3-1 through Figure 3-5.

For the remainder of the report, the following references will be used for these tubes:

Tube 1: ASME calibration tube shown in Figure 3-1.

Tube 2: EDM notch standard with circumferential and axial notches shown in Figure 3-2.

Tube 3: EDM notch standard with only axial EDM notches shown in Figure 3-3. This tube also has four 100% deep notches at one axial location, but circumferentially separated by 90 degrees between each notch. The tube also contains four 20% deep OD notches at one axial location with 90 degree circumferential separation between each notch.

Tube 4: EDM notch standard with only circumferential EDM notches shown in Figure 3-4.

Tube 5: Calibration tube for X-Probes shown in Figure 3-5. It contains mechanically rolled expansion, 20% deep OD groove, 30% deep OD groove, carbon steel ring and 40% deep spiral groove.

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Figure 3-1
ASME Calibration Tube (This Tube Design is Referred to as "Tube 1" in the "Master" Set of Calibration Tubes)

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Figure 3-2
EDM Notch Standard for Rotating and Array Eddy Current Probes

(This Tube Design is Referred to as "Tube 2" in the "Master" Set of Calibration Tubes)

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Figure 3-3
Tube with Only Axial EDM Notches for Bobbin, Rotating and Array Probes

(This Tube Design is Referred to as "Tube 3" in the "Master" Set of Calibration Tubes)

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Figure 3-4
Calibration Tube with Only Circumferential EDM Notches for Rotating and Array Eddy Current Probes

(This Tube Design is Referred to as "Tube 4" in the "Master" Set of Calibration Tubes)

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Figure 3-5
Calibration Tube Used for Setting Up Eddy Current Array Probes Similar to X-Probes

(This Tube Design is Referred to as "Tube 5" in the "Master" Set of Calibration Tubes)

4 PERFORMANCE DEMONSTRATION REQUIREMENTS

The performance demonstration involves comparing calibration tube flaw signals from the new proposed technique with signals from common flaws generated by a corresponding qualified inspection technique. The signals from the proposed technique must be obtained from selected flaws in the master set of calibration tubes documented in Section 3. The signals from the qualified techniques can be obtained either by setting up the qualified techniques to scan the appropriate tubes from the master set of calibration tubes, or from calibration tube scans from archived data acquired with the qualified techniques. EPRI has stored the data used for technique qualification with the qualified ETSS documentation.

There are two criteria required for performance demonstration of equivalency between a proposed technique and a qualified technique. One criterion is to demonstrate that the proposed technique will generate an equivalent or larger flaw signal amplitude from the probe (eddy current interaction with the flaw), before normalization, as the qualified technique. When the signal amplitude from a new technique is significantly lower than the amplitude of the qualified technique, the system is forced to significantly increase amplification of the signals for analysis. The increased amplification often amplifies the background system noise. This can lead to decreased signal-to-noise ratio and decreased detection capability. Demonstrating that the new proposed technique will generate equivalent flaw signal amplitude from the probe with the corresponding qualified technique will mitigate the possibility of increasing the system noise. If the "qualified" data channel of the technique is a frequency mix, then this amplitude criterion must apply to each of the component frequencies of the mix.

The second criterion is to demonstrate that the proposed technique will generate equivalent flaw signals (amplitude and phase) from a comprehensive set of calibration tube flaws after the signals have been normalized according to practices in analysis set-ups. This criterion will verify that the proposed technique can characterize flaws in an equivalent manner as the corresponding qualified technique. Tolerances for allowable variations in signals that can be defined as "equivalent" have be determined by examining flaw signal variances in multiple calibration tube scans performed using the qualified techniques.

4.1 Bobbin Probe Techniques

For bobbin probe techniques scanning equivalent diameter tubes as signal comparisons should be done using the localized flaws in ASME calibration tubes.

Because some bobbin probe techniques have been qualified on several tube dimensions at once, careful consideration must be used when examining the ASME through-wall hole signals for tubes with outside diameter (OD) 0.75" and smaller, and tubes with larger diameters. For tubes with OD ≤ 0.75", the diameter of the through-wall hole is 0.052". For tubes with OD > 0.75", the diameter of the hole is 0.067".

If the diameter of tubing inspected with the new proposed technique is equivalent to tube dimensions used with a qualified bobbin probe technique, then to verify that the new technique generates equivalent amplitude as the qualified technique, it is recommended to demonstrate this using signals from the four 20% deep flat bottom holes in Tube 1 (the ASME calibration tube) shown in Figure 3-1.

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If the diameter of tubing inspected with the new proposed technique is equivalent to tube dimensions used with a qualified bobbin probe technique, then to verify that the new technique generates equivalent relative signal responses as a qualified technique, then a comparison of the signals from the flat bottom holes and the 100% deep through-hole in Tube 1 (the ASME calibration tube) should be performed as a minimum.

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These tolerances allow for signal variances that can occur due to tolerances in machined flaw dimensions and typical variations in tube wall thickness, as well as tolerances in eddy current probe dimensions and probe centering. These tolerances are within observed variances generated by fully qualified bobbin probe techniques.

4.2 Rotating Eddy Current Probe Techniques

The capability of a new proposed technique to generate an equivalent or larger (not normalized) flaw signal should be demonstrated using signals from a 100% deep, 0.375" long axial EDM notch. Examples are flaw "K" in Tube 2, shown in Figure 3-2, and flaw "E" in Tube 3, shown in Figure 3-3.

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The capability of a new proposed technique to generate equivalent signals (amplitude and phase) on a comprehensive set of flaws should be demonstrated using the 40, 60 and 100% deep axial and circumferential EDM notches in Tube 2, or in Tubes 3 and 4. 20% deep EDM notches are often too small to generate clear repetitive signals for demonstrating equivalency.

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4.3 Eddy Current Array Coil Probe Techniques

The capability of a new proposed technique to generate an equivalent or larger (not normalized) flaw signal should be demonstrated using signals from a 100% deep, 0.375" long axial EDM notch. Examples are flaw "K" in Tube 2, shown in Figure 3-2, and flaw "E" in Tube 3, shown in Figure 3-3. If the array probe uses different groups of coils for detecting axial and circumferential flaws, then the capability of a proposed to generate signals from circumferential flaws of equal or greater amplitude as generated by a qualified technique should be evaluated using a 100% deep, 0.375" long circumferential EDM notch. Examples are flaw "D" in Tube 2, or flaw "D" in Tube 4.

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The capability of a new proposed technique to generate equivalent signals (amplitude and phase) on a comprehensive set of flaws should be demonstrated using the 40, 60 and 100% deep axial and circumferential EDM notches in Tube 2, or in Tubes 3 and 4. 20% deep EDM notches are often too small to generate clear repetitive signals for demonstrating equivalency.

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4.4 Calibrating X-Probes

The EPRI qualified ETSS's for operating general purpose X-Probes (Eg. ETSS 20400) require amplitude calibration on a 20% deep OD axially symmetric groove, allowing a variance in axial extent from 0.25" to 0.5".

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5 EQUATIONS

5.1 Characteristic Parameter Governing Probe Coil Impedance/Voltage

Maintaining perfect equivalence between different test systems requires maintaining consistency of the characteristic parameter as defined by Dodd and others [2] in the equation below:

$$P_c = f\sigma\mu l^2 \qquad \text{Eq. 5-1}$$

Where l represents the linear scale of the probe coils, test tubes, flaws and all other materials. σ is the electrical conductivity and μ is the magnetic permeability of the tube material. The electrical conductivity is the reciprocal of the electrical resistivity of a material:

$$\sigma = \frac{1}{\rho} \qquad \text{Eq. 5-2}$$

Where ρ is electrical resistivity.

5.2 Tube Wall Thickness to Electromagnetic Skin Depth Ratio

Often, the most important essential parameters for eddy current inspection are the material properties of the inspected tubes and there wall thicknesses. These parameters govern the penetration of the eddy current into the tube wall.

For most practical situations, it is often sufficient to maintain a consistent wall thickness to skin depth ratio in establishing "equivalent" eddy current techniques for testing tubes of different wall thicknesses.

$$R = \tau / \delta \qquad \text{Eq. 5-3}$$

Where τ is the tube wall thickness and δ is the electromagnetic skin depth of penetration.

$$\delta = \sqrt{\frac{2}{2\pi f \sigma \mu}} \qquad \text{Eq. 5-4}$$

Where σ is the electrical conductivity and μ is the magnetic permeability of the tube material.

To date, all EPRI qualified eddy current techniques for steam generator tube inspection are qualified for only nonferromagnetic tubes. The equation for choosing an equivalent frequency for testing a tube with a different wall thickness is as follows:

$$f_2 = f_1 \frac{\sigma_1 \tau_1^2}{\sigma_2 \tau_2^2} \qquad \text{Eq. 5-5}$$

Where the subscript 1 identifies the variables (frequency, electrical conductivity and wall thickness) of the qualified technique and subscript 2 identifies the variables in the equivalent technique. If a new proposed technique is used for inspecting tubing with a different wall thickness or material conductivity from tubing used with a qualified technique, then Equation 5-5 can be used to specify a new frequency used to set up an equivalent channel as used with a qualified technique.

6 ESSENTIAL VARIABLE DISCUSSION

Essential variables are those parameters of the inspection technique that when affected could have an impact on the performance of the technique. This includes such system components as the instrument, the software, the probe, signal cables, and calibration standards. Parameters such as tester architecture, software version, probe length, coil dimensions, coil windings, cable length, cable resistance/capacitance, and calibration standard artifact dimensions all have potential impact to the performance of a qualified technique. An "Essential Variables Workbook" is provided to assist with and ensure that each of the appropriate essential variables is properly addressed in an equivalency demonstration.

6.1 Essential Variables Workbook Description

The Essential Variables Workbook is located in Appendix A of this document. Below the original technique number, column (1) identifies the list of essential variables considered during the initial qualification of a technique. Column (2) provides the as qualified value of each variable. Column (3) lists the acceptable variable value ranges. Column (4) provides reference to the methods which were used to measure the value of each variable. Below the proposed technique, column (5) lists the variable values of the new technique for each required essential variable. Column (6) references how the equivalency was demonstrated.

Table 6-1
Layout of Workbook Table

Essential Variables	EPRI Appendix H Qualified Original ETSS: ____			Proposed Technique:	
	Value(s) as Qualified	Essential Variable Ranges/Values	Method of Measurement	Essential Variable Values	Method of Demonstrating Equivalency
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6

6.2 Using the Table

Fill in each column with the appropriate values derived from the qualified technique or as determined from an analysis of the intended application. An example is provided in Appendix A.

6.3 Identifying Essential Variables

Each qualified technique should have an associated list of essential variables and their values as qualified. In addition, the allowable ranges that would have to be met should be given. In the cases where all of the essential variables were not identified in the original technique qualification report, they will have to be retroactively identified and measured using the original systems and qualified techniques. Where it is impossible to recreate the original systems, a written justification report will be generated which cites theory and perhaps uses computer modeling as evidence of equivalency or by using more available systems that previously demonstrated equivalency to the original systems.

7 REFERENCES

1. *Pressurized Water Reactor Steam Generator Examination Guidelines: Revision 7*: EPRI, Palo Alto, CA: 2007. 1013706.
2. Dodd C.V., "The Use of Computer-Modeling for Eddy Current Testing", Research Techniques in Nondestructive Testing, Vol. III, edited by R.S. Sharpe, Academic Press Limited, London, pp. 242-479, 1977.

A
ESSENTIAL VARIABLES WORKBOOK

Table A-1
Essential Variables Workbook

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Table A-1 (continued)
Essential Variables Workbook

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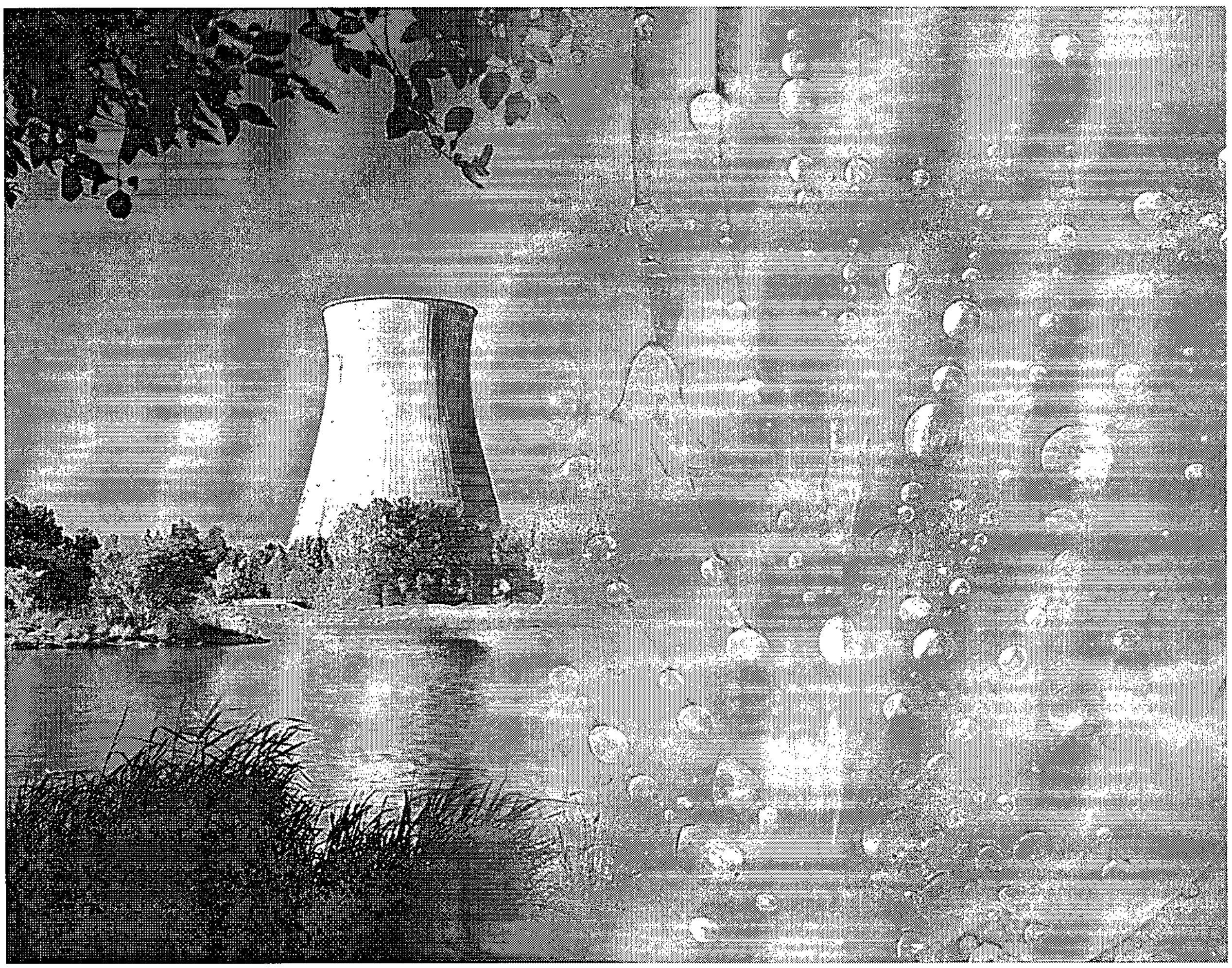
Steam Generator Management Program: Development of Standardized Process for Determining Examination Technique Equivalency

1018557



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Technical Update, March 2009

EPRI Project Manager

T. Bipes

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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Zetec, Inc.
8226 Bracken PL SE Suite 100
Snoqualmie, WA 98065

Principal Investigator
S. Sullivan

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PRODUCT DESCRIPTION

Utilities use qualified techniques when performing eddy-current tests on nuclear power plant steam generator (SG) tubes. When components of the "qualified" system are changed, verification of equivalency to the originally qualified system must be performed. This report describes the intermediate results of the Electric Power Research Institute's (EPRI's) ongoing multiyear project that includes the development of a simplified, cost-effective method of determining eddy-current technique and substitute component equivalency.

The EPRI PWR Steam Generator Examination Guidelines require that examination technique specification sheets (ETSSs) define essential variables for equipment, techniques, and analysis. Examination techniques with essential variables that vary within the ranges identified in the ETSS are considered equivalent.

In order to take advantage of technology advances in nondestructive examination (NDE) techniques and equipment, utilities must demonstrate technique or system component equivalency prior to implementation. The convention has been that each individual utility requires the inspection organization to develop the technical basis and assemble the required documentation that demonstrates technique or substitute component equivalency as part of their inspection services contract. The elaborate process currently performed to document equivalency has resulted in increased cost to the utilities involved. A simplified, cost-effective process for determination of examination technique equivalency could provide financial benefits to utilities.

Results and Findings

In a previous report for this project (EPRI Report 1015126, *Development of a Process for Determining Examination Technique Equivalency*), a proposed method was documented for demonstrating equivalency between EPRI-qualified eddy-current inspection techniques for SG tubes and similar inspection techniques with modified essential variables. The equivalency demonstration requires two components. One component is an engineering technical justification explaining why the changes in essential variables should not affect the performance of the technique in detecting and characterizing SG tube flaws. The other component is a practical demonstration showing that the modified techniques can generate equivalent signals from selected calibration tube flaws as the qualified techniques.

This report documents a review of various EPRI-qualified techniques compared to field techniques with modified essential variables. The effect that changes in essential variable tolerances have on the resulting eddy-current signal is also documented.

Challenges and Objectives

This report provides information useful to the SG program owner and supporting NDE professional for developing validation documentation for site inspection techniques with modified essential variables. Continued work will provide further documentation of the practical use of the proposed equivalency technique and the effect of changes to essential variables on the resulting eddy-current signal. Benefits of this project include 1) providing a consistent and cost-effective method to evaluate system performance, technique performance, and substitute component equivalency and 2) assembling equivalency documentation on various SG eddy-current inspection techniques.

EPRI Perspective

The determination of SG eddy-current technique equivalency has been an involved and costly process. The development of a standardized and efficient process for determining eddy-current technique and substitute component equivalency should provide cost savings to utilities and allow the determination of equivalency to be made in a much shorter period.

Approach

Investigators developed a written plan for documenting equivalency for new examination techniques, in which essential variables may be outside of the range of those defined in the originating ETSS. Measurement and acceptance of essential variables for the technique, individual system components, and analysis were to be considered in accordance with EPRI's Steam Generator Examination Guidelines.

Investigators developed a process in which a utility engineer or a vendor organization could set up an identical examination system, as planned for field use, test a calibration standard flaw(s) or master sample, and immediately determine whether the system is "equivalent" to currently qualified systems. System performance would be evaluated as a whole rather than trying to evaluate each of the individual system elements. A method to standardize the evaluation of system performance was developed in order to achieve consistent eddy-current results.

In the final steps, investigators designed and produced a master set of flawed tube samples that could be used to perform examination technique equivalency checks. A procedure was developed for using the master samples to demonstrate examination technique equivalency.

Keywords

Steam generators
Essential variables
Eddy-current inspection
Examination technique specification sheet (ETSS)

CONTENTS

1 INTRODUCTION

Improving the quality of PWR steam generator inspection is an evolutionary process. As new techniques are developed qualification cost can be sustainably reduced by proper implementation of a standardized process for determining examination technique equivalency. If an existing qualified technique, documented with an examination technique specification sheets (ETSS's) is identified to be acceptably equivalent to a new technique, then this system can be documented as being qualified when the standardized process is applied.

Requirements on how eddy current inspection techniques should be qualified for inspecting steam generator tubes is provided in Appendix H of *Steam Generator Management Program: Pressurized Water Reactor Steam Generator Examination Guidelines: Revision 7* [1]. A framework for determining a recommended procedure on demonstrating technique equivalency was developed by EPRI in *Development of a Process for Determining Examination Technique Equivalency* [2].

This report provides a detailed review of essential variables described in the recommendation report. This review provides the essential variable tolerance bases for applying the recommended procedure in a demonstration of ETSS equivalency methodology. This demonstration could be looked upon as an example of the standardized process for determining examination technique equivalency.

2
INFLUENCES OF ESSENTIAL VARIABLE TOLERANCES ON EDDY CURRENT TECHNIQUES INSPECTION PERFORMANCE

2.1 Introduction

Equipment and technique variables are defined and reported as a single value, range of values, or formula for a specific technique in an ETSS. This set of variables, used to document the details of a specific technique, are termed essential in Appendix H of Reference 1. For determining equivalency these essential variables reduced down to controlling parameters associated with three physical attributes.

- Eddy Current Penetration
- Array Probe Coverage Crossover Variations
- Cable Length Variances

These tolerances of essential variables that influence each of these attributes are investigated and described in this section.

2.2 Eddy Current Penetration

The tolerance on penetration of the eddy current density due to variations in operating frequency, test material resistivity or material thickness is ±10% of the qualified value as specified by Section H.4.1.2 in Reference 1. The relative eddy current density is calculated using the following approximation equation:

$$J(x)/J_0 = e^{-x/\delta}$$

Equation 2-1

where $J(x)$ is the eddy current density at location x inside the conducting tube wall and J_0 is the magnitude of the eddy current density on the surface of the tube wall closest to the probe coil(s) (the ID surface). The ±10% is to be applied to the position (x) on the tube wall OD surface of the tube wall. Consequently, the value of x should be equal to the thickness of the tube wall.

The eddy current skin depth of penetration δ is expressed by Equation 2-2 as follows:

$$\delta = \sqrt{\frac{2\rho}{2\pi f\mu}}$$

Equation 2-2

where f is the operating frequency, ρ is the electrical resistivity of the material and μ is the magnetic permeability of the material. For nonferromagnetic material where $\mu = \mu_0$, the magnetic permeability of free space, Equation 2-2 can be simplified as shown in Equation 2-3 as follows:

$$\delta = 1.98\sqrt{\frac{\rho}{f}}$$

Equation 2-3

where δ is in units of inches, ρ is in $\mu\Omega$-cm and f is in Hz.

2.2.1 Computer Simulation Methodology for Eddy Current Transmit-Receive Array Probes

X-Probes are eddy current probes that are used for inspecting steam generator and heat exchanger tubes. They are capable of detecting and characterizing circumferentially and axially oriented flaws such as cracks, and volumetric flaws such as those caused by corrosion or mechanical fretting.

As shown in Figure 2-1, X-probes are composed of an array of pancake eddy current coils. These probe coils are magnetically coupled in transmit-receive configurations with laterally spaced transmit and receive coils. Transmit (active primary) coils are driven by time harmonic alternating current at several frequencies simultaneously. Receive (passive secondary) coils generate a voltage equal to the time-rate-of-change of magnetic flux through the coil windings.

Because the coils are configured in this type of transmit-receive configuration, they are directionally sensitive. One set of coils are used to detect axially oriented flaws such as axial cracks. Another set of coils are used to detect circumferentially oriented flaws. Both the axial and circumferential coil sets are generally capable of detecting flaws that have no directional preference such as volumetric flaws, intergranular attack (IGA) or multi-directional cracks.

Closed form solutions to Maxwell's electromagnetic equations as applied to low frequency eddy current coils had been developed by Dodd and Deeds [3] for pancake coils near flat plates and by Dodd, Cheng and Deeds [4] for bobbin coils inside and encircling coaxial metallic tubes. In calculating solutions for transmit-receive coil geometries, the free-space coil component of the Dodd and Deeds equations was subtracted from the overall solution. As suggested by Fisher, Cain and Beissner [5], a Biot-Savart free-space coil solution was added to replace the Dodd and Deeds free-space coil component.

The solutions to transmit-receive pancake coils near flat plates have been used to calculate the electromagnetic fields generated by the X-Probe coils, and these solutions have been applied to the tubular geometries using conformal mapping. This method of using simulations of pancake coils near flat plates and applying these solutions to pancake coil tubes is an approximation because the model does not consider coils being tilted with respect to each other in the tubes.

To calculate the probe responses to localized flaws, the first order approximation proposed by Nair and Rose [6] has been used for small semicircular infinitesimally thin (crack-like) flaws. This model is consistent with models proposed by Dodd, Deeds and Luguire [7], and Auld, Muennemann and Riaziat [8].

For crack-like flaws with a finite length, eddy current responses to several semicircular shaped crack-like flaws were added to simulate the response to rectangular profiled flaws as shown in Figure 2-1. The semicircles overlapped each-other by one half of a circle radius to compensate for empty spaces left in the arrangement. The equation used in this approximation to calculate probe response to such a crack-like flaw is:

$$\Delta V = \frac{4}{3} \times \frac{8}{9} \times \frac{\sigma}{2I_R} \int_0^L E_y^T(x) E_y^R(x) D(x)^2 \, dx$$

Equation 2-4

ΔV is the change in probe voltage as the probe scans the section of tube with the flaw in it. $D(x)$ is the flaw depth at position x. σ is the electrical conductivity of the tube being scanned. $E_y^T(x)$ is the electric field component perpendicular to the plane of the flaw at linear horizontal position x generated by the current in the transmit coil. $E_y^R(x)$ is the electric field component perpendicular to the plane of the flaw at linear horizontal position x generated by a "virtual" current (I_R) in the receive coil. The vertical depth positions for the electric field calculations in this equation are at 20% of the flaw depth from the side of the conducting wall nearest to the probe coils.

This eddy current model for calculating flaw signals is only valid if the flaw depth is not significantly deeper than the eddy current skin depth of penetration in the conducting tube wall. If the flaw is significantly longer than the tube wall thickness, then the model is only valid for partially through-wall flaws. Equation 2-4 does not properly simulate the physics of the eddy current interaction with a long flaw that is 100% through the tube wall over a significant distance along the tube.

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Figure 2-1
Diagram of an X-Probe Coil Layout – Particular Design in this Figure is for 12.7 mm (0.5 Inch) Diameter Monel 400 Steam Generator Tubes

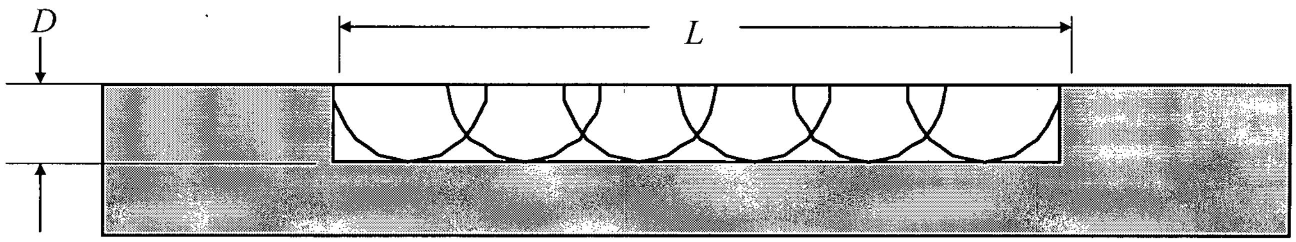

Figure 2-2
Diagram Showing Technique of Modeling Eddy Current Signal Response to Rectangular Crack-Like Flaw Using Series of Semicircular Crack-Like Flaws – Radius of the Semicircles is Equal to the Flaw Depth

2.2.2 Validation of Computer Simulations of Eddy Current Transmit-Receive Probes

Figure 2-3 shows calculated signals from an X-Probe detecting circumferential crack-like flaws in 0.75" (1.81 cm) diameter by 0.043" (1.092 mm) wall Inconel 600 tubes at 300 kHz test frequency. Figure 2-4 shows peak-to-peak voltage measurements of signals calculated from X-Probe coils detecting circumferential ID crack-like flaws compared with signal voltage measurements from laboratory X-Probe scans of 0.75" (1.81 cm) diameter by 0.043" (1.092 mm) wall Inconel 600 tubes with circumferential ID EDM notches at 300 kHz test frequency. Figure 2-5 shows peak-to-peak voltage measurements of signals calculated from X-Probe coils detecting circumferential OD crack-like flaws compared with signal voltage measurements from laboratory X-Probe scans of 0.75" (1.81 cm) diameter by 0.043" (1.092 mm) wall Inconel 600 tubes with circumferential OD EDM notches at 300 kHz test frequency. Figure 2-6 shows peak-to-peak phase measurements of signals calculated from X-Probe coils detecting circumferential ID and OD crack-like flaws compared with signal phase measurements from laboratory X-Probe scans of 0.75" (1.81 cm) diameter by 0.043" (1.092 mm) wall Inconel 600 tubes with circumferential ID and OD EDM notches at 300 kHz test frequency. These notches were 0.375" long. The laboratory data used to evaluate the effectiveness of the models was procured from calibration tube scans in EPRI's archived qualification data for X-Probes.

The comparisons of the laboratory signal measurements and the measurements of the mathematically simulated signals shown in Figures 2-4 though 2-6 indicate that the model is adequately simulating the physical effects that generate the observed signals.

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Figure 2-3
Voltage Plane Display of Calculated X-Probe Signals from Circumferential Crack-Like Flaws in 0.75" (1.81 cm) diameter by 0.043" (1.092 mm) Wall Inconel 600 Tubes at 300 KHz Test Frequency

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Figure 2-4
Peak-to-Peak Voltage Measurements of Signals Calculated from X-Probe Coils Detecting Circumferential ID Crack-Like Flaws Compared with Signal Voltage Measurements of Laboratory X-Probe Scans from 0.75" (1.81 cm) diameter by 0.043" (1.092 mm) Wall Inconel 600 Tubes with Circumferential ID EDM Notches at 300 KHz Test Frequency (Notches were 0.375" (9.525 mm) Long, Voltage Measurements have been Scaled Based on Setting the Signal from a 20% Deep OD Groove to 2 Volts-PP)

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Figure 2-5
Peak-to-Peak Voltage Measurements of Signals Calculated from X Probe Coils Detecting Circumferential OD Crack-Like Flaws Compared with Signal Voltage Measurements from Laboratory X-Probe Scans of 0.75" (1.81 cm) diameter by 0.043" (1.092 mm) Wall Inconel 600 Tubes with Circumferential OD EDM Notches at 300 KHz Test Frequency (Notches were 0.375" (9.525 mm) Long, Voltage Measurements have been Scaled Based on Setting the Signal from a 20% Deep OD Groove to 2 Volts-PP)

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Figure 2-6
Peak-to-Peak Phase Measurements of Signals Calculated from X Probe Coils Detecting Circumferential ID and OD Crack-Like Flaws Compared with Signal Phase Measurements from Laboratory X-Probe Scans of 0.75" (1.81 cm) diameter by 0.043" (1.092 mm) Wall Inconel 600 Tubes with Circumferential ID and OD EDM Notches at 300 KHz Test Frequency (Notches were 0.375" (9.525 mm) Long, Display has been Rotated to Orient the Signal from Lift-Off (Tube Expansion) to 0 Degrees)

2.2.3 Signal-to-Noise Ratio and Detection Capability

Detection capability is dependent on the amplitudes of the signals generated by the probes detecting flaws in comparison to the background noise. There are generally two components of noise that can influence detection capability.

One component of noise is the system noise which is generally electrical. This component of noise can often be generated by intermittent ground contacts, the eddy current instrument itself, or it can be picked up from the electrical system supplying power to the inspection system. This component of noise is generally overcome by strong signal responses from the flaws.

The other component of noise is generally called "tube" noise which is background signals from the probe detecting signals from variations in tube geometry, support structures, and conducting or magnetic deposits. When tube noise is dominant, increasing signal strength is not effective in improving detection capability because when signal strength is increased, the amplitude of the background noise increases proportionally with the amplitude of the flaw signals. Generally, the most prominent component of the tube noise is generated by variations in tube geometry such as denting, bulging and expansions. Background noise from probes detecting support structures can be minimized using frequency mixing. When appropriate inspection frequencies are chosen, signals from deposits are usually much weaker than those from tube geometry variations. For this reason, the most common practice in inspections is to rotate the phase angle of the lift-off noise horizontal on the voltage plane display. However, the voltage plane trace signals from variable coil lift-off are always slightly curved, so even when the signal is rotated horizontal, there is always a small residual vertical component to the noise.

2.2.4 X-Probe Detection Capability as a Function of Eddy Current Depth of Penetration

For simulating changes in the electromagnetic penetration, two ways of changing the relative current density were examined: One method examined the effect of decreasing the resistivity of the tube material to a degree where the relative current density as defined by Equation (2-1) was reduced by 10%. For X-Probe techniques qualified for testing tubes at 300 kHz test frequency in tubes with wall thickness of 0.043" (1.092 mm) and material resistivity equal to about 100 μΩ-cm, this worked out to reducing the tube material resistivity to 84 μΩ-cm. The other method evaluated was the effect of increasing tube wall thickness to a point where the relative current density as defined by equation (2.1) was reduced by 10%. For X-Probe techniques qualified for testing tubes at 300 kHz test frequency in tubes with wall thickness of 0.043" (1.092 mm) and material resistivity equal to about 100 μΩ-cm this worked out to increasing the tube wall thickness to 0.0468" (1.1887 mm).

The effect of reducing the resistivity of the tube material was examined first. Flaw signals from tube material with resistivity of 100 μΩ-cm were compared with flaw signals in tubes of the same dimensions, but with resistivity of 84 μΩ-cm at 300 kHz test frequency.

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A summary of the changes in flaw signal measurements due to this variation in tube material resistivity is listed in Table 2.4.1. The computer simulation was used to determine how much deeper the flaws would be to produce equivalent size signals as in the original case.

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. It is worth noting that with modern instrumentation, the drive voltage can be increased to compensate for the decrease in signal amplitude caused by using the technique on a lower resistivity tube. If the dominant component of noise is system noise, then increasing the drive voltage would enable the technique applied to the lower resistivity tube to achieve an equivalent POD performance as the original qualified technique.

In this case (with reduced material resistivity), signal to noise ratios were also calculated assuming that the dominant noise would be variances in coil to tube wall proximity (lift-off). In tube testing, this type of situation can often occur due to variations in tube geometry, transverse motion of the probe head, dents and tube expansions. The signal from a 0.008" (0.203 mm) change in lift-off was calculated in 0.002" (0.051 mm) steps. This curved signal was rotated horizontally on a voltage display, and the residual vertical component of this signal was calculated after it was rotated. The residual vertical component of the lift-off signal was used as the "noise" in the signal-to-noise ratio calculations. Table 2.4.2 is a listing of signal measurements and signal-to-noise ratio calculations as functions of flaw depth and tube material resistivity. The computer simulation was then used to determine how much deeper the flaws would be (in a tube with material resistivity equal to 84 μΩ-cm) to produce signals where the signal-to-noise ratios would be equivalent to the original case (tube material resistivity = 100 μΩ-cm).

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The effects of reducing the relative electromagnetic penetration by leaving the resistivity constant, but making the tube wall thicker were also examined.

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A summary of the changes in flaw signal measurements due to this increase in tube wall thickness is listed in Table 2.4.3. The computer simulation was used to determine how much deeper the flaws would be (in a tube with wall thickness = 0.0468" (1.1887 mm)) to produce equivalent size signals as in the original case (tube wall thickness = 0.043" (1.092 mm)).

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Table 2.4.4 is a listing of signal measurements and signal-to-noise ratio calculations as functions of flaw depth and tube wall thickness. The computer simulation was then used to determine how much deeper the flaws would be (in a tube with wall thickness = 0.0468" (1.1887 mm)) to produce signals where the signal-to-noise ratios would be equivalent to the original case (tube wall thickness = 0.043" (1.092 mm)).

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Table 2-1
Calculated Changes in Signals from X-Probes Detecting Circumferential Crack-Like Flaws Due to a Decrease in Tube Material Resistivity

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Note: Flaws were 0.375" (9.525 mm) Long, Test Frequency was 300 kHz

Table 2-2
Calculated Changes in Signal-to-Noise Ratios from X-Probes Detecting Circumferential Crack-Like Flaws Due to a Decrease in Tube Material Resistivity

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Note: Flaws were 0.375" (9.525 mm) Long, Test Frequency was 300 kHz

Table 2-3
Calculated Changes in Signal-to-Noise Ratios from X-Probes Detecting Circumferential Crack-Like Flaws Due to an Increase in Tube Wall Thickness

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Note: Flaws were 0.375" (9.525 mm) Long, Test Frequency was 300 kHz

Table 2-4
Calculated Changes in Signal-to-Noise Ratios from X-Probes Detecting Circumferential Crack-Like Flaws Due to an Increase in Tube Wall Thickness

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Note: Flaws were 0.375" (9.525 mm) Long, Test Frequency was 300 kHz

2.2.5 Computer Simulation Methodology for Bobbin Eddy Current Probes

Closed form solutions to Maxwell's electromagnetic equations as applied to low frequency eddy current coils had been developed by Dodd, Cheng and Deeds [4] for bobbin coils inside and encircling coaxial metallic tubes.

To calculate the probe responses to localized flaws, the first order approximation proposed by Nair and Rose [6] has been used for small semicircular infinitesimally thin (crack-like) flaws, and for small semispherical volumetric flaws. These models are consistent with models proposed by Dodd and Deeds [7].

For axial crack-like flaws with a finite length, eddy current responses to several semicircular shaped crack-like flaws were added to simulate the response to rectangular profiled flaws as shown in Figure 2-1. The semicircles overlapped each-other by one half of a circle radius to compensate for empty spaces left in the arrangement. The equation used in this approximation to calculate bobbin impedance coil responses to such a crack-like flaw is:

$$\Delta Z_i = \frac{4}{3} \times \frac{8}{9} \times \frac{\sigma}{2I^2} \int_0^L E_y^T(x)^2 (x) D(x)^2 \, dx$$

Equation 2-5

ΔZ_i is the change in probe impedance as the probe scans the section of tube with the flaw in it. $D(x)$ is the flaw depth at position x. σ is the electrical conductivity of the tube being scanned. $E_y^T(x)$ is the electric field component perpendicular to the plane of the flaw at linear horizontal position x generated by the current in the transmit coil. The vertical depth positions for the electric field calculations in this equation are at 20% of the flaw depth from the side of the conducting wall nearest to the probe coils.

For localized shallow geometry changes, the first order approximation proposed by Nair and Rose [6] has been used for small semispherical volumetric flaws and localized wall thickness increases. These models are consistent with models proposed by Dodd and Deeds [7]. The specific equation is listed below:

$$\Delta Z_i = \pm \frac{3}{2} (Vol) \frac{\sigma}{I^2} E^2$$

Equation 2-6

In this equation, Vol is the volume of the flaw and E is the magnitude of the electric field that would have been generated by the coil at the location of the flaw if the flaw was absent. For this equation to be valid, the radius of the flaw must be much smaller than the wall thickness of the tube and the electromagnetic skin depth of penetration. This equation can be used to calculate a signal from a localized decrease or increase in wall thickness. Signals from shallow changes in wall thickness, which extend over significant distances axially and/or circumferentially, can be determined by summing changes from several individual semispherical components that have been determined using Equation 2-6. A localized dent can be calculated as a combination of a wall loss on the OD of the tube and equivalent increase in wall thickness on the ID of the tube. An expansion or bulge in the tube can be calculated as a combination of a wall thickness increase on the OD of the tube and a wall loss on the ID of the tube.

For the differential bobbin coil configuration, the signal is equal to the difference in the impedance changes of the two coils.

$$\Delta Z = \Delta Z_1 - \Delta Z_2$$ **Equation 2-7**

2.2.6 Validation of Computer Simulations of Bobbin Eddy Current Probes

The mathematical simulations were applied to calculating signals from differential bobbin probes in 0.75" diameter by 0.043" (1.092 mm) wall steam generator tubes with material resistivity of 100 μΩ-cm at 400 kHz test frequency detecting shallow expansions, and axially aligned crack-like flaws. These signals were compared with calibration signals from laboratory scans of 0.75" (19.05 mm) diameter by 0.43" (10.92 mm) wall Inconel 600 calibration tubes calibration tubes. Figure 2-7 shows comparisons of signal shapes and relative phase orientation between an expansion and a 40% deep OD axial crack-like flaw.

Graphs of peak-to-peak voltage and phase measurements of signals from axial crack-like flaws are shown in Figures 2-8, 2-9 and 2-10. The comparisons of the laboratory signal measurements and the measurements of the mathematically simulated signals shown in these figures indicate that the model is adequately simulating the physical effects that generate the observed signals.

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Figure 2-7
(a) Calculated Impedance Plane Signal from a Differential Bobbin Probe Detecting a 0.002" Diameter Expansion in a 0.75" (19.05 mm) Diameter by 0.43" (10.92 mm) Wall Steam Generator Tube at 400 kHz; (b) Calculated Signal from the Differential Bobbin Probe Detecting a 40% Deep OD Axial Crack-Like Flaw that is 0.375" (9.535 mm) Long at 400 kHz; (c) Signal from a 0.016" (0.406 mm) Expansion from a Laboratory Scan of a Calibration Tube with at 400 kHz; (d) Signal from a 40% Deep OD Axial EDM Notch from Laboratory Scan of a Calibration Tube with at 400 kHz

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Figure 2-8
Comparisons of Peak-to-Peak Voltage Measurements of Differential Bobbin Probe Signals from ID Axial Crack-Like Flaws of Various Depths Generated by a Mathematical Simulation and Laboratory Measurements (Inconel 600 Tube with a Diameter of 0.75" (19.05 mm) and Wall Thickness of 0.043" (1.092 mm), Test Frequency was 400 kHz – Voltage Measurements have been Scaled Based on Setting the Signal from the 60% Deep OD Axial EDM Notch to 2.7 Volts-PP)

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Figure 2-9
Comparisons of Peak-to-Peak Voltage Measurements of Differential Bobbin Probe Signals from OD Axial Crack-Like Flaws of Various Depths Generated by a Mathematical Simulation and Laboratory Measurements (Inconel 600 Tube with a Diameter of 0.75" (19.05 mm) and Wall Thickness of 0.043" (1.092 mm), Test Frequency was 400 kHz – Voltage Measurements have been Scaled Based on Setting the Signal from the 60% Deep OD Axial EDM Notch to 2.7 Volts-PP)

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Figure 2-10
Comparisons of Peak-to-Peak Phase Measurements of Differential Bobbin Probe Signals from ID and OD Axial Crack-Like Flaws of Various Depths Generated by a Mathematical Simulation and Laboratory Measurements (Inconel 600 Tube with a Diameter of 0.75" (19.05 mm) and Wall Thickness of 0.043" (1.092 mm), Test Frequency was 400 kHz – Orientation Setting of the Display is Based on Setting the Peak-to-Peak Phase of the Tube Expansion Signal 5 Degrees)

2.2.7 Bobbin Probe Detection Capability as a Function of Eddy Current Depth of Penetration

The effect of decreasing the resistivity of the tube material to a degree where the relative current density as defined by Equation 2-1 was reduced by 10% was examined. Bobbin probe techniques most commonly use 400 kHz as the primary test frequency for testing steam generator tubes.

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A summary of the changes in flaw signal measurements due to this variation in tube material resistivity is listed in Table 2-5. The computer simulation was used to determine how much deeper the flaws would be to produce equivalent size signals as in the original case. Generally the flaws would have had to have been about 3% (through-wall) deeper.

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In this case (with reduced material resistivity), signal to noise ratios were also calculated assuming that the dominant noise would be generated by variances in coil to tube wall proximity (lift-off). In tube testing, this type of situation can often occur due to transverse motion of the probe head, dents and tube expansions. The signal from an expansion with a change in diameter of 0.002" (0.051 mm) was calculated. This curved signal was rotated horizontally on a voltage display, and the residual vertical component of this signal was calculated after it was rotated. The residual vertical component of the expansion signal was used as the "noise" in the signal-to-noise ratio calculations. Table 2-6 is a listing of signal measurements and signal-to-noise ratio calculations as functions of flaw depth and tube material resistivity. The computer simulation was then used to determine how much deeper the flaws would be (in a tube with material resistivity equal to 86 μΩ-cm) to produce signals where the signal-to-noise ratios would be equivalent to the original case (tube material resistivity = 100 μΩ-cm).

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Table 2-5
Calculated Changes in Signals from Differential Bobbin Probes Detecting Axial Crack-Like Flaws Due to a Decrease in Tube Material Resistivity

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Note: Flaws were 0.375" (9.525 mm) Long, Test Frequency was 400 kHz

Table 2-6
Calculated Changes in Signal-to-Noise Ratios from Differential Bobbin Probes Detecting Axial Crack-Like Flaws Due to a Decrease in Tube Material Resistivity

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Note: "Noise" is Quantified as the Residual Vertical Component of a 0.02" (0.508 mm) Long Expansion with a 0.002" (0.051 mm) Increase in Tube Diameter, Flaws were 0.375" (9.525 mm) Long, Test Frequency was 400 kHz, Orientation of the Impedance Plane Signal Display is Set for the Expansion Signal to Be Horizontal

2.3 Array Probe Coverage Crossover Variations

Section H.4.1.3 of the EPRI Pressurized Water Reactor Steam Generator Examination Guidelines [1] specifies that the array probe crossover amplitude should not decrease by more than 10% compared with the crossover value of the originally qualified technique. These guidelines define coverage, and the value and location of the crossover by the signal amplitude profile of 0.080" (2.032 mm) long, 60% deep EDM notches that are oriented in the appropriate directions. For example, the coverage profile for coils detecting circumferential flaws should be obtained from measurements using circumferential EDM notches. Coverage profiles for coils detecting axial flaws should be obtained from measurements using axial EDM notches.

The mathematical simulation method described in Section 2.2.1 of this report was applied to evaluate variances in coverage crossover for the circumferentially aligned transmit-receive coil pairs in the qualified X-Probe designs.

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An example of a circumferential amplitude profile is shown in Figure 2-11.

A variance in the crossover location and value was considered by determining the shift in the location where the crossover value decreased by 10%. In practice this could occur when the pancake coils are not properly aligned on the array probe.

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Figure 2-11
Amplitude Profiles of Circumferential Transmit-Receive Coils of an X-Probe Detecting 0.080" (2.032 mm) Long Circumferential Flaws (300 kHz Operating Frequency)

2.4 Cable Length Variances

Eddy current scan data was acquired with variations in extension cable lengths. The data was acquired from a 120' (37 m) long bobbin probe with no extension cable, with a 50' (15 m) long extension cable attached, and with two 50' (15 m) long (total 100' (30 m)) extension cables attached.

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In examining this data, the only real change observed was a change in the absolute amplitude of the signals. There was no change in the signals beyond standard variations due to repeatability after they had been normalized (Eg. setting the 4 by 20% flat bottom holes signal to 4 Volts-PP and setting the through-wall hole signal to 40 degrees). Table 2-6 is a listing of signal measurements from a 120' (37 m) long bobbin probe with and without extension cables attached. Scans were made with no extension cable, a 50' length of low-loss extension cable, and with two 50' (15 m) lengths (total 100' (30 m)) of low-loss extension cables.

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From this it is concluded that if tube noise (Eg. dent, ding, expansion, deposit and/or support structure signals) are the dominant source of noise, then these variations in extension cables will have no effect on detection capability (POD) or sizing accuracy. Table 4.1 is a listing of signal measurements from a 120' (37 m) long bobbin probe with and without extension cables attached. Scans were made with no extension cable, a 50' (15 m) length of low-loss extension cable, and with two 50' (15 m) lengths (total 100' (30 m)) of low-loss extension cables.

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Normalization was performed with one scan data file and the recorded signal measurements were performed using the other two scans.

An equation based on known circuit parameters (Eg. cable capacitance, coil inductance) was used to calculate how the swept frequency plots would behave. Figure 2-12 is a diagram of a representative circuit that can be used to evaluate how cable capacitance and probe coil inductance contribute to signal amplitude.

ω is the angular frequency (equal to $2\pi f$). j is the imaginary constant (equal to the square root of -1). R_S is the output resistance of the eddy current instrument, R_C is the resistance of the coil, L is the inductance of the coil and C is the capacitance of the probe cables and extension cables.

The circuit model determines the amplitude of the current that reaches the probe coil which determines the strength of the signal from the flaw as a function of operating frequency. One shortcoming of this circuit model is that it assumes that the coil resistance and inductance are constant over the frequency range. However, when a probe coil is in a tube, the eddy current generated in the tube can affect the coil inductance and resistance.

This circuit model was applied to evaluating the effect of adding extension cables to the bobbin probe system. Figures 2-14 and 2-14 show the effects of adding 50' (15 m) and 100' (30 m) of low-loss extension cables to a bobbin probe system.

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It is worth noting that with modern instrumentation, the drive voltage can be increased to compensate for the decrease in signal amplitude caused the longer extension cables. If the dominant component of noise is system noise, then increasing the drive voltage could enable the technique applied with longer extension cables to achieve an equivalent POD performance as the original qualified technique. The use of a probe with lower inductance coils could also mitigate the reduction in signal amplitude caused by additional extension cable length.

Table 2-7
Listing of signal measurements from a 120' (37 m) long bobbin probe with and without extension cables attached

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Note: Scans were made with no extension cable, a 50' (15 m) length of low-loss extension cable, and with two 50' (15 m) lengths (total 100' (30 m)) of low-loss extension cables. The signals were normalized by setting the peak-to-peak voltages of the signals from the 4 by 20% deep ASME holes to 4 Volts, and the phase of the ASME through-wall hole signal to 40 degrees. The calibration tube scans were performed in groups of three. Normalization was performed with one scan data file and the recorded signal measurements were performed using the other two scans.

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Figure 2-12
Amplitude Profiles of Circumferential Transmit-Receive Coils of an X-Probe Detecting 0.080" (2.032 mm) Long Circumferential Flaws (300 kHz Operating Frequency)

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Figure 2-13
Swept Frequency Plot for a Bobbin Probe System with no Extension Cables, and with 50' (15 m) Long Low-Loss Extension Cables Based on the Circuit Model (Scaled Measurements of Differential Bobbin Probe Signals from an ASME ID Groove are Superimposed on the Graph)

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Figure 2-14
Swept Frequency Plot for a Bobbin Probe System with no Extension Cables, and with 100' (30 m) Long Low-Loss Extension Cables Based on the Circuit Model (Scaled Measurements of Differential Bobbin Probe Signals from an ASME ID Groove are Superimposed on the Graph)

2.5 Summary/Conclusions

This section documents the effects of variances in essential variables on inspection performance of some eddy current inspection techniques for testing steam generator tubes. It was observed that variances in essential variables could degrade inspection performance as compared with strict qualified techniques. However, if the variances in essential variables are kept within the tolerances specified by section H.4 in appendix H or the EPRI Pressurized Water Reactor Steam Generator Examination Guidelines: Revision 7 [1], the degradation in inspection performance should not be serious.

Studies of the effects of reduced penetration of electromagnetic field into the tube wall due to either reduced material resistivity or increase tube wall thickness indicated that the probability of detection (POD) would not be shifted horizontally by more than 3% tube wall thickness if the change was kept within the tolerance specified in section H.4 of the EPRI Guidelines [1].

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A variance in the crossover location and value was considered by determining the shift in the location where the crossover value decreased by 10%. In practice this could occur when the pancake coils are not properly aligned on the array probe.

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An evaluation of the effects of adding lengths of extension cables to a bobbin probe technique showed that, as expected, this did not affect the relative (normalized) signals, but only the raw signals. Therefore, if tube noise (eg. signals from dents, expansions, deposits or support structures) is the dominant component of noise, then the addition of extension cables would not affect the probe's detection capability.

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3 FIELD DEMONSTRATION OF RECOMMENDED ETSS EQUIVALENCY DEMONSTRATION METHODOLOGY

3.1 Introduction

Appendix H of the EPRI Pressurized Water Reactor Steam Generator Examination Guidelines contains requirements on how eddy current inspection techniques should be qualified for inspecting steam generator tubes [1]. Qualified techniques are documented in examination technique specification sheets (ETSS's) that record the essential variables that are used by the techniques, and performance parameters such as probability of detection (POD) and sizing accuracy of the techniques.

For practical purposes, inspection vendors are often unable to comply with the essential variable requirements for qualified techniques needed for an inspection. One example where this can happen is when a technique has been qualified using an eddy current instrument such as a MIZ18, that is generally unavailable at the present time due to obsolescence. Another example is when an inspection is needed for Inconel 690 tubing, but the technique has been qualified for detecting and/or sizing flaws in Inconel 600 tubing. In these types of cases where it is impossible to use properly qualified techniques for an inspection, a demonstration of technique equivalency can show that modified techniques will be equally effective in detecting and/or sizing flaws as the qualified techniques.

Appendix H of the EPRI Pressurized Water Reactor Steam Generator Examination Guidelines also contains some requirements on demonstrating equivalency between qualified techniques and alternate techniques that may be deployed by inspection vendors [1]. However, there have been concerns raised about the effectiveness of these equivalency demonstration requirements [9]. In addition, utilities have expressed a desire to make the process of demonstrating equivalency less exacting and therefore cumbersome. To address these concerns, a recommended procedure on demonstrating technique equivalency was developed in 2007 and documented in EPRI report 1015126 [2].

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These listed techniques are qualified for detecting flaws in Inconel 600 tubes. Since the techniques deployed in replacement SG tubes are used for detecting flaws in different tube material (Inconel 690), they cannot be considered as qualified, so equivalency demonstrations are required to show that these techniques can detect and/or size flaws as well as the qualified techniques. Because of this, data from recent inspections of replacement SG's was considered useful in evaluating the new equivalency demonstration procedure. It should be noted that the acceptability of these techniques for inspecting the Inconel 690 replacement tubes had already been established and documented in a site validation document, following the recommendations in the Steam Generator Examination Guidelines [1].

As part of the procedure documented in EPRI report 1015126, signal comparisons between the qualified techniques and the alternate techniques are required. A comparison of "raw" (non-normalized) signals is required to ensure that the alternate techniques are generating a comparable amplitude level of eddy current interaction with the flaws as generated by the qualified techniques. This is a test to minimize the possibility of a significant increase in system noise generated by the alternate techniques. In addition, a comparison of normalized signals from a comprehensive set of common flaws is required to ensure equivalence in the eddy current density (flow direction and relative depth of penetration) generated by the qualified and proposed alternate techniques.

"Raw" signal readings depend on the signal from the probe cable, the instrument gain, and the built in gain in the display software. Using the same software to display the "raw" signals eliminates differences that could be caused by the software display gain. Differences in instrument amplification gains need to be accounted for when comparing "raw" signal readings. A change in drive voltage makes a real change in the amplitude of the signal at the probe head. However, the instrument gain has no influence on the signal at the probe head, but it does influence the final reading obtained in the display software.

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3.2 Bobbin Probe Comparisons

For bobbin probe techniques scanning equivalent diameter tubes as signal comparisons should be done using the localized flaws in ASME calibration tubes.

Because some bobbin probe techniques have been qualified on several tube dimensions at once, careful consideration must be used when examining the ASME through-wall hole signals for tubes with outside diameter (OD) 0.75" (19.05 mm) and smaller, and tubes with larger diameters. For tubes with OD ≤ 0.75" (19.05 mm), the diameter of the through-wall hole is 0.052" (1.321 mm). For tubes with OD > 0.75" (19.05 mm), the diameter of the hole is 0.067" (1.702 mm).

If the diameter of tubing inspected with the new proposed technique is equivalent to tube dimensions used with a qualified bobbin probe technique, then to verify that the new technique generates equivalent amplitude as the qualified technique, it is recommended to demonstrate this using signals from the four 20% deep flat bottom holes in an ASME calibration tube.

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This tolerance is within observed variances generated by fully qualified bobbin probe techniques.

If the diameter of tubing inspected with the new proposed technique is equivalent to tube dimensions used with a qualified bobbin probe technique, then to verify that the new technique generates equivalent relative signal responses as a qualified technique, then a comparison of the signals from the flat bottom holes and the 100% deep through-hole in an ASME calibration tube should be performed as a minimum. If the tube dimensions are different where the diameter of the through-holes are changed in the ASME tubes used to calibrate the bobbin probes, then only comparisons of the signals from the ASME flat bottom holes (not the 100% through-holes) are necessary.

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These tolerances allow for signal variances that can occur due to tolerances in machined flaw dimensions and typical variations in tube wall thickness, as well as tolerances in eddy current probe dimensions and probe centering. These tolerances are within observed variances generated by fully qualified bobbin probe techniques.

3.2.1 ETSS 96004

A listing of the differences in essential variables between the qualified ETSS 96004 and the bobbin probe technique deployed in replacement SG tubes is listed in Table 3-1.

Calibration tube data from the qualified bobbin technique was procured from the EPRI qualification database for ETSS 96004. Calibration tube data from the replacement SG technique was acquired at an inspection of the unit in October 2006.

Table 3-2 is a listing of comparisons of "raw" voltage measurements made on signals from the 4 by 20% deep flat bottom holes. The qualified channel in ETSS 96004.1 is a differential 400-100 kHz frequency mix channel. The corresponding channel used in the thinner wall, higher resistivity replacement SG tubing was a differential 750-190 kHz frequency mix channel. To verify equivalency, it is desired to demonstrate that each of the component frequency channels used in the mix channels of the proposed technique should be comparable in magnitude to the corresponding component channels used in the qualified frequency mix channel.

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Table 3-3 is a summary of the comparison of normalized signals from the flat bottom holes in ASME calibration tubes used to calibrate the bobbin probes. In this case, the data channels that were compared were the 400-100 kHz frequency mix in the qualified technique with the differential 750-190 kHz mix used. The differences ("errors") were smaller than the allowable tolerances documented in the proposed process for demonstrating technique equivalency documented in EPRI report number 1015126 [2]. A typical signal from the 60% deep ASME flat bottom hole detected by the bobbin probe used is shown in Figure 3-5. A typical signal from the 60% deep ASME flat bottom hole detected by the bobbin technique qualified in accordance with ETSS 96004.1 is shown in Figure 3-6.

The signal comparisons between the techniques have passed the "raw" voltage criteria, and the normalized signal criteria documented in EPRI report number 1015126 [2], so this bobbin probe technique deployed in these replacement SG tubes can be considered equivalent to the qualified bobbin technique documented in ETSS 96004.1.

Table 3-1
Listing of Signal Measurements from a 120' (37 m)Long Bobbin Probe with and without Extension Cables Attached

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Table 3-2
Comparison of Peak-to-Peak Voltage Measurements from 4×20% Deep Flat Bottom Hole Signals in ASME Calibration Tubes Used at the Unit with the Replaced SG's, and from the 4×20% Deep Flat Bottom Hole Signals Used by the Qualified Technique ETSS 96004.1

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Table 3-3
Comparison of Measurements from Various Flat Bottom Hole Signal Signals from an ASME Calibration Tube at a Field Inspection, and from ASME Flat Bottom Hole Signals Used by the Qualified Technique ETSS 96004.1

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These signal readings were based on normalizing the voltage of the 4×20% deep flat bottom hole signal to 4 Volts-PP, and rotating the MxR phase of the 100% deep through-hole signal to 40 degrees in each case.

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Figure 3-1
"Raw" (Not Normalized) 750 kHz Differential Signal from Bobbin Probe Detecting the 4 X 20% Deep Flat Bottom Holes in an Inconel 690 ASME Calibration Tube (Signal was Acquired Using a TC7700 Eddy Current Instrument at a Gain of 41 dB, Drive Voltage was 10 V-p)

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Figure 3-2
"Raw" (Not Normalized) 190 kHz Differential Signal from Bobbin Probe Detecting the 4 X 20% Deep Flat Bottom Holes in an Inconel 690 ASME Calibration Tube (Signal was Acquired Using a TC7700 Eddy Current Instrument at a Gain of 41 dB, Drive Voltage was 10 V-p)

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Figure 3-3
"Raw" (Not Normalized) 400 kHz Differential Signal from Bobbin Probe Detecting the 4 X 20% Deep Flat Bottom Holes in an Inconel 600 ASME Calibration Tube Used in the EPRI Qualification Data Used with ETSS 96004 (Signal was Acquired Using a MIZ18A Eddy Current Instrument)

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Figure 3-4
"Raw" (Not Normalized) 400 kHz Differential Signal from Bobbin Probe Detecting a 4 X 20% Deep ASME Flat Bottom Hole in an Inconel 600 ASME Calibration Tube Used in the EPRI Qualification Data Used with ETSS 96004 (Signal was Acquired Using a MIZ18A Eddy Current Instrument)

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Figure 3-5
Normalized Differential 750-190 kHz Frequency Mix Signal from Bobbin Probe Detecting a 60% Deep Flat Bottom Hole in an Inconel 690 ASME Calibration Tube (Signal has been Normalized by Setting the MxR Phase of the 100% through-Hole Signal to 40 Degrees and Setting the Voltage of the Signal from the 4×20% Deep Flat Bottom Holes to 4 Volts-PP)

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Figure 3-6
Normalized Differential 400-100 kHz Frequency Mix Signal from Bobbin Probe Detecting a 60% Deep Flat Bottom Hole in an Inconel 600 ASME Calibration Tube Used in EPRI Qualification Data for ETSS 96004 (Signal has been Normalized by Setting the MxR Phase of the 100% through-Hole Signal to 40 Degrees and Setting the Voltage of the Signal from the 4×20% Deep Flat Bottom Holes to 4 Volts-PP)

3.2.2 ETSS 96008

A listing of the differences in essential variables between the qualified ETSS 96008.1 and the bobbin probe technique deployed in replacement SG tubes is listed in Table 3-4.

Calibration tube data from the qualified bobbin technique was procured from the EPRI qualification database for ETSS 96008. Calibration tube data from the replacement SG technique was acquired at an inspection of the unit with replaced SG's.

Table 3-5 is a listing of comparisons of "raw" voltage measurements made on signals from the 4 by 20% deep flat bottom holes. The qualified channel in ETSS 96008.1 is a differential 400-100 kHz frequency mix channel. The corresponding channel used in the thinner wall, higher resistivity replacement SG tubing was a differential 750-190 kHz frequency mix channel. To verify equivalency, it is desired to demonstrate that each of the component frequency channels used in the mix channels of the proposed technique should be comparable in magnitude to the corresponding component channels used in the qualified frequency mix channel.

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Table 3-6 is a summary of the comparison of normalized signals from the flat bottom holes in ASME calibration tubes used to calibrate the bobbin probes. In this case, the data channels that were compared were the 400-100 kHz frequency mix in the qualified technique with the differential 750-190 kHz mix used. The differences ("errors") were smaller than the allowable tolerances documented in the proposed process for demonstrating technique equivalency documented in EPRI report number 1015126 [2]. An example of a signal from the Bobbin technique using a 750-190 kHz frequency mix detecting a 60% deep OD flat bottom hole in an ASME calibration tube is shown in Figure 3-5. This signal can be compared with a corresponding 400-100 kHz frequency mix signal from a 60% deep OD ASME flat bottom hole in a calibration tube used by the bobbin technique ETSS 96008.1 in Figure 3-9.

The signal comparisons between the techniques have passed the "raw" voltage criteria, and the normalized signal criteria documented in EPRI report number 1015126 [2], so this bobbin probe technique deployed in these replacement SG tubes can be considered equivalent to the qualified bobbin technique documented in ETSS 96008.1.

Table 3-4
Listing of Essential Variable Differences between a Bobbin Probe Technique Using Data Acquired at the Unit with Replacement SG's, and the EPRI Qualified Technique ETSS 96008

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ETSS 96008.1 (R14, Aug. 2006)

Table 3-5
Comparison of Peak-to-Peak Voltage Measurements from 4×20% Deep Flat Bottom Hole Signals in ASME Calibration Tubes Used at the Unit with the Replaced SG's, and from the 4×20% Deep Flat Bottom Hole Signals Used by the Qualified Technique ETSS 96008.1

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Table 3-6
Comparison of Measurements from Various Flat Bottom Hole Signals from an ASME Calibration Tube Used at the Unit with the Replaced SG's in October 2006, and from ASME Flat Bottom Hole Signals Used by the Qualified Technique ETSS 96008.1

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Note: These signal readings were based on normalizing the voltage of the 4×20% deep flat bottom holes to 4 Volts-PP, and rotating the MxR phase of the 100% deep through-hole to 40 degrees in each case.

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Figure 3-7
"Raw" (Not Normalized) 400 kHz Differential Signal from Bobbin Probe Detecting the 4 X 20% Deep Flat Bottom Holes in an Inconel 600 ASME Calibration Tube Used in the EPRI Qualification Data Used with ETSS 96008 (Signal was Acquired Using a MIZ18 Eddy Current Instrument)

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Figure 3-8
"Raw" (Not Normalized) 100 kHz Differential Signal from Bobbin Probe Detecting the 4 X 20% Deep Flat Bottom Holes in an Inconel 600 ASME Calibration Tube Used in the EPRI Qualification Data Used with ETSS 96008 (Signal was Acquired Using a MIZ18 Eddy Current Instrument)

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Figure 3-9
Normalized Differential 400-100 kHz Frequency Mix Signal from Bobbin Probe Detecting a 60% Deep Flat Bottom Hole in an Inconel 600 ASME Calibration Tube Used in EPRI Qualification Data for ETSS 96008 (Signal has been Normalized by Setting the MxR Phase of the 100% through-Hole Signal to 40 Degrees and Setting the Voltage of the Signal from the 4×20% Deep Flat Bottom Holes to 4 Volts-PP.)

3.2.3 ETSS 96012

A listing of the differences in essential variables between the qualified ETSS 96012.1 and the bobbin probe technique deployed in replacement SG tubes is listed in Table 3-7.

Calibration tube data from the qualified bobbin technique was procured from the EPRI qualification database for ETSS 96012. Calibration tube data from the replacement SG technique was acquired at an inspection of the unit with the replaced SG's.

Table 3-8 is a listing of comparisons of "raw" voltage measurements made on signals from the 4 by 20% deep flat bottom holes. The qualified channels in ETSS 96012.1 are a differential 400-100 kHz frequency mix channel and an absolute 400-100 kHz frequency mix channel. The corresponding channels used in the thinner wall, higher resistivity replacement SG tubing was a differential 750-190 kHz frequency mix channel and an absolute 750-190 kHz frequency mix channel. To verify equivalency, it is desired to demonstrate that each of the component frequency channels used in the mix channels of the proposed technique should be comparable in magnitude to the corresponding component channels used in the qualified frequency mix channel. Therefore, the magnitudes of the differential and absolute 190 kHz signals from the 4 by 20% deep flat bottom holes of the bobbin technique used were compared with the magnitudes of the corresponding flaw signals of the qualified technique at 100 kHz. In addition, the magnitudes of the differential and absolute 750 kHz signals from the 4 by 20% deep flat bottom holes of the bobbin technique used were compared with the magnitudes of the corresponding flaw signals of the qualified technique at 400 kHz.

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Table 3-9 is a summary of the comparison of normalized signals from the flat bottom holes in ASME calibration tubes used to calibrate the bobbin probes. In this case, the data channels that were compared were the differential and absolute 400-100 kHz frequency mix channels in the qualified technique with the differential and absolute 750-190 kHz mix channels used. Because the qualification data was acquired in 0.875" (22.225 mm) OD tubing, the ASME through-hole was significantly larger than the through-hole used in the 0.625" (15.875 mm) OD ASME calibration tube used. Because these were different diameter holes, the signals from these holes were not included in the comparison in Table 3-9. The differences ("errors") were smaller than the allowable tolerances documented in the proposed process for demonstrating technique equivalency documented in EPRI report number 1015126 [2]. An example of a signal from the bobbin technique using a 750-190 kHz frequency mix detecting a 60% deep OD flat bottom hole in an ASME calibration tube is shown in Figure 3-5. This signal can be compared with a corresponding 400-100 kHz frequency mix signal from a 60% deep OD ASME flat bottom hole in a calibration tube used by the bobbin technique ETSS 96012.1 in Figure 3-16. A normalized 750-190 kHz frequency mix absolute signal from a 60% deep OD ASME calibration flat bottom hole used is shown in Figure 3-17. This signal can be compared with the normalized 400-100 kHz frequency mix absolute signal from the 60% deep OD ASME flaw used by the ETSS 96012.1 bobbin technique shown in Figure 3-18.

The signal comparisons between the techniques have passed the "raw" voltage criteria, and the normalized signal criteria documented in EPRI report number 1015126 [2], so this bobbin probe technique deployed in these replacement SG tubes can be considered equivalent to the qualified bobbin technique documented in ETSS 96012.1.

Table 3-7
Listing of Essential Variable Differences between a Bobbin Probe Technique Using Data Acquired at the Unit with the Replaced SG's, and the EPRI Qualified Technique ETSS 96012

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ETSS 96012.1 (R11, Aug. 2006)

Table 3-8
Comparison of Peak-to-Peak Voltage Measurements from 4×20% Deep Flat Bottom Hole Signals in ASME Calibration Tubes at the Unit with the Replaced SG's, and from the 4×20% Deep Flat Bottom Hole Signals Used by the Qualified Technique ETSS 96012.1

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Table 3-9
Comparison of Signal Measurements from Various Flat Bottom Holes from ASME Calibration Tubes Used at the Unit with the Replaced SG's, and from ASME Flat Bottom Holes Used by the Qualified Technique ETSS 96012.1

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These signal readings were based on normalizing the voltage of the 4×20% deep flat bottom holes to 4 Volts-PP, and rotating the MxR phase of the 100% deep through-hole to 40 degrees in each case

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Figure 3-10
"Raw" (Not Normalized) 400 kHz Differential Signal from Bobbin Probe Detecting the 4 X 20% Deep Flat Bottom Holes in an Inconel 600 ASME Calibration Tube Used in the EPRI Qualification Data Used with ETSS 96012 (Signal was Acquired Using a MIZ30A Eddy Current Instrument Operating with a Gain of ×2 (36 dB) and a Drive Voltage of 12 Volts-PP)

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Figure 3-11
"Raw" (Not Normalized) 100 kHz Differential Signal from Bobbin Probe Detecting the 4 X 20% Deep Flat Bottom Holes in an Inconel 600 ASME Calibration Tube Used in the EPRI Qualification Data Used with ETSS 96012 (Signal was Acquired Using a MIZ30A Eddy Current Instrument Operating with a Gain of ×2 (36 dB) and a Drive Voltage of 12 Volts-PP)

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Figure 3-12
"Raw" (Not Normalized) 750 kHz Absolute Signal from Bobbin Probe Detecting the 4 X 20% Deep Flat Bottom Holes in an Inconel 690 ASME Calibration Tube (Signal was Acquired Using a TC7700 Eddy Current Instrument at a Gain of 41 dB and a Drive Voltage was 10 V-p)

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Figure 3-13
"Raw" (Not Normalized) 190 kHz Absolute Signal from Bobbin Probe Detecting the 4 X 20% Deep Flat Bottom Holes in an Inconel 690 ASME Calibration Tube (Signal was Acquired Using a TC7700 Eddy Current Instrument at a Gain of 41 dB and a Drive Voltage was 10 V-p)

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Figure 3-14
"Raw" (Not Normalized) 400 KHz Absolute Signal from Bobbin Probe Detecting the 4 X 20% Deep Flat Bottom Holes in an Inconel 600 ASME Calibration Tube Used in the EPRI Qualification Data Used with ETSS 96012 (Signal was Acquired Using a MIZ30A Eddy Current Instrument Operating with a Gain of ×2 (36 dB) and a Drive Voltage of 12 Volts-PP)

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Figure 3-15
"Raw" (Not Normalized) 100 kHz Absolute Signal from Bobbin Probe Detecting the 4 X 20% Deep Flat Bottom Holes in an Inconel 600 ASME Calibration Tube Used in the EPRI Qualification Data Used with ETSS 96012 (Signal was Acquired Using a MIZ30A Eddy Current Instrument Operating with a Gain of ×2 (36 dB) and a Drive Voltage of 12 Volts-PP)

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Figure 3-16
Normalized Differential 400-100 kHz Frequency Mix Signal from Bobbin Probe Detecting a 60% Deep Flat Bottom Hole in an Inconel 600 ASME Calibration Tube Used in EPRI Qualification Data for ETSS 96012 (Signal has been Normalized by Setting the MxR Phase of the 100% through-Hole Signal to 40 Degrees and Setting the Voltage of the Signal from the 4×20% Deep Flat Bottom Holes to 4 Volts-PP)

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Figure 3-17
Normalized Absolute 750-190 kHz Frequency Mix Signal from Bobbin Probe Detecting a 60% Deep Flat Bottom Hole in an Inconel 690 ASME Calibration Tube (Signal has been Normalized by Setting the Peak-to-Peak Phase of the 100% through-Hole Signal to 40 Degrees and Setting the Voltage of the Signal from the 4×20% Deep Flat Bottom Holes to 4 Volts-PP)

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Figure 3-18
Normalized Absolute 400-100 kHz Frequency Mix Signal from Bobbin Probe Detecting a 60% Deep Flat Bottom Hole in an Inconel 600 ASME Calibration Tube Used in EPRI Qualification Data for ETSS 96012 (Signal has been Normalized by Setting the Peak-to-Peak Phase of the 100% through-Hole Signal to 40 Degrees and Setting the Voltage of the Signal from the 4×20% Deep Flat Bottom Holes to 4 Volts-PP)

3.3 Rotating Probe Comparisons

The capability of a new proposed technique to generate equivalent or larger (not normalized) flaw signal should be demonstrated using signals from a 100% deep, 0.375" (9.525 mm) long axial EDM notch.

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The capability of a new proposed technique to generate equivalent signals (amplitude and phase) on a comprehensive set of flaws should be demonstrated using 0.375" (9.525 mm) long ID and OD 40, 60 and 100% deep axial and circumferential EDM notches. 20% deep EDM notches are often too small to generate clear repetitive signals for demonstrating equivalency.

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3.3.1 ETSS 20510 and ETSS 21409

A listing of the differences in essential variables between the qualified ETSS 20510 and the Plus-Point rotating probe technique deployed in replacement SG tubes is listed in Table 3-10. A listing of the differences in essential variables between the qualified ETSS 21409 and the Plus-Point rotating probe technique deployed in replacement SG tubes is listed in Table 3-11.

Calibration tube data from the qualified Plus-Point was acquired at Zetec in the "master" tube samples that were manufactured as part of the 2007 work done in the ETSS Equivalency project. Calibration tube data from the replacement SG technique was acquired at an inspection of the unit with the replaced SG's.

Table 3-12 is a listing of comparisons of "raw" voltage measurements made on signals from the 100% deep axial and circumferential EDM notches.

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These signals can be compared with the "raw" 200 kHz signals from data acquired from a plus-point technique qualified in accordance with ETSS 20510 and 21409 detecting 100% deep axial and circumferential EDM notches shown in Figures 3-21 and 3-22.

Table 3-13 is a summary of the comparison of normalized signals from calibration EDM notches acquired from scans using the qualified technique, and the Plus-Point technique used in the replacement SG tubes. The differences ("errors") were smaller than the allowable tolerances documented in the proposed process for demonstrating technique equivalency documented in EPRI report number 1015126 [2]. Normalized signals from 40% deep OD axial calibration EDM notches at 300 kHz with the plus-point technique and at 200 kHz with a plus-point technique qualified in accordance with ETSS 20510 and 21409 are shown in Figures 3-23 and 3-24. Normalized signals from 60% deep ID circumferential calibration EDM notches at 300 kHz with the plus-point technique and at 200 kHz with a plus-point technique qualified in accordance with ETSS 20510 and 21409 are shown in Figures 3-25 and 3-26.

The signal comparisons between the techniques have passed the "raw" voltage criteria, and the normalized signal criteria documented in EPRI report number 1015126 [2], so this 300 kHz channel from the rotating Plus-Point technique deployed in these replacement SG tubes can be considered equivalent to the 200 kHz channel in the qualified techniques ETSS 20510 and ETSS 21409 according to this proposed equivalency demonstration process.

Table 3-10
Listing of Essential Variable Differences between the Plus-Point Rotating Probe Technique Deployed at the Unit with the Replaced SG's, and the EPRI Qualified Technique ETSS 20510

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ETSS #:20510 (R7, 2006)

Table 3-11
Listing of Essential Variable Differences between the Plus-Point Rotating Probe Technique Deployed at the Unit with the Replaced SG's, and the EPRI Qualified Technique ETSS 21409

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ETSS #:21409 (R5, 2006)

Table 3-12
Comparison of Peak-to-Peak Voltage Measurements from 100% Deep Axial and Circumferential EDM Notch Signals from Calibration Tubes Used at the Unit with the Replaced SG's, and from Techniques Considered Qualified in Accordance with ETSS 20510.1 and 21409.1

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Table 3-13
Comparison of Signal Measurements from Various EDM Notches from Calibration Tubes Used at the Unit with the Replaced SG's, and from Techniques Considered Qualified in Accordance with ETSS 20510.1 and 21409.1

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These signal readings were based on normalizing the voltage of the 100% deep axial EDM notch to 20 Volts-PP, and rotating the phase of the 40% deep axial ID EDM notch to 15 degrees in each case.

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Figure 3-19
"Raw" (Not Normalized) 300 kHz Signal from a Rotating Plus-Point Detecting a 100% Deep Axial EDM Notch in an Inconel 690 Calibration Tube (Signal was Acquired Using a TC7700 Eddy Current Instrument Operating with a Gain of 41 dB and a Drive Voltage of 10 Volts-P)

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Figure 3-20
"Raw" (Not Normalized) 300 kHz Signal from a Rotating Plus-Point Detecting a 100% Deep Circumferential EDM Notch in an Inconel 690 Calibration Tube (Signal was Acquired Using a TC7700 Eddy Current Instrument Operating with a Gain of 41 dB and a Drive Voltage of 10 Volts-P)

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Figure 3-21
"Raw" (Not Normalized) 200 kHz Signal from a Rotating Plus-Point Detecting a 100% Deep Axial EDM Notch in an Inconel 600 Calibration Tube Used in Data Acquired with a Qualified Technique in Accordance with ETSS 20510 and ETSS 21409 (Signal was Acquired Using a MIZ30 Eddy Current Instrument Operating with a Gain of "×2" and a Drive Voltage of 12 Volts-PP)

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Figure 3-22
"Raw" (Not Normalized) 200 kHz Signal from a Rotating Plus-Point Detecting a 100% Deep Circumferential EDM Notch in an Inconel 600 Calibration Tube Used in Data Acquired with a Qualified Technique in Accordance with ETSS 20510 and ETSS 21409 (Signal was Acquired Using a MIZ30 Eddy Current Instrument Operating with a Gain of "×2" and a Drive Voltage of 12 Volts-PP)

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Figure 3-23
Normalized 300 kHz Signal from a Rotating Plus-Point Probe Detecting a 40% Deep OD Axial EDM Notch in an Inconel 690 Calibration Tube (Signal has been Normalized by Setting the Peak-to-Peak Phase of the 40% Deep ID Axial EDM Notch Signal to 15 Degrees and Setting the Voltage of the Signal from the 100% Deep Axial EDM Notch to 20 Volts-PP)

Content deleted - EPRI Proprietary Information

Figure 3-24
Normalized 200 kHz Signal from a Rotating Plus-Point Probe Detecting a 40% Deep OD Axial EDM Notch in an Inconel 600 Calibration Tube Used in Data Acquired with a Qualified Technique in Accordance with ETSS 20510 and ETSS 21409 (Signal has been Normalized by Setting the Peak-to-Peak Phase of the 40% Deep ID Axial EDM Notch Signal to 15 Degrees and Setting the Voltage of the Signal from the 100% Deep Axial EDM Notch to 20 Volts-PP)

Content deleted - EPRI Proprietary Information

Figure 3-25
Normalized 300 kHz Signal from a Rotating Plus-Point Probe Detecting a 60% Deep ID Circumferential EDM Notch in an Inconel 690 Calibration Tube (Signal has been Normalized by Setting the Peak-to-Peak Phase of the 40% Deep ID Axial EDM Notch Signal to 15 Degrees and Setting the Voltage of the Signal from the 100% Deep Axial EDM Notch to 20 Volts-PP)

Content deleted - EPRI Proprietary Information

Figure 3-26
Normalized 200 kHz Signal from a Rotating Plus-Point Probe Detecting a 60% Deep ID Axial EDM Notch in an Inconel 600 Calibration Tube Used in Data Acquired with a Qualified Technique in Accordance with ETSS 20510 and ETSS 21409 (Signal has been Normalized by Setting the Peak-to-Peak Phase of the 40% Deep ID Axial EDM Notch Signal to 15 Degrees and Setting the Voltage of the Signal from the 100% Deep Axial EDM Notch to 20 Volts-PP)

3.3.2 ETSS 21998

A listing of the differences in essential variables between the qualified ETSS 21998 and the Plus-Point rotating probe technique deployed in replacement SG tubes is listed in Table 3-14.

Calibration tube data from the qualified Plus-Point was acquired at Zetec in the "master" tube samples that were manufactured as part of the 2007 work done in the ETSS Equivalency project. Calibration tube data from the replacement SG technique was acquired at an inspection of the unit with the replaced SG's.

Table 3-15 is a listing of comparisons of "raw" voltage measurements made on signals from the 100% deep axial and circumferential EDM notches.

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Table 3-16 is a summary of the comparison of normalized signals from calibration EDM notches acquired from scans using the qualified technique, and the Plus-Point technique used in the replacement SG tubes. The differences ("errors") in signal phases from the OD EDM notches were larger than the allowable tolerances documented in the proposed process for demonstrating technique equivalency documented in EPRI report number 1015126 [2]. Normalized signals from 40% deep OD axial calibration EDM notches at 300 kHz with the plus-point technique and at 300 kHz with a plus-point technique qualified in accordance with ETSS 21998 are shown in Figures 3-23 and 3-29 respectively.

The signal comparisons between the techniques have passed the "raw" voltage criteria documented in EPRI report number 1015126 [2], especially when the signals from the inspection have been re-scaled to show readings at an equivalent gain as used with the signals from the qualified technique.

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Table 3-14
Listing of Essential Variable Differences between the Plus-Point Rotating Probe Technique Deployed at the Unit with the Replaced SG's, and the EPRI Qualified Technique ETSS 21998

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Table 3-15
Comparison of Peak-to-Peak Voltage Measurements from 100% Deep Axial and Circumferential EDM Notches from Calibration Tubes Used at the Unit with the Replaced SG's, and from Techniques Considered Qualified in Accordance with ETSS 21998.1

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Table 3-16
Comparison of Signal Measurements from Various EDM Notches from Calibration Tubes Used at the Unit with the Replaced SG's, and from Techniques Considered Qualified in Accordance with ETSS 21998.1

Content deleted - EPRI Proprietary Information

These signal readings were based on normalizing the voltage of the 100% deep axial EDM notch to 20 Volts-PP, and rotating the phase of the 40% deep axial ID EDM notch to 15 degrees in each case. Signal measurements that are out of tolerance for technique equivalency are high-lighted in grey

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Figure 3-27
"Raw" (Not Normalized) 300 kHz Signal from a Rotating Plus-Point Detecting a 100% Deep Axial EDM Notch in an Inconel 600 Calibration Tube Used in Data Acquired with a Qualified Technique in Accordance with ETSS 21998. This Signal was Acquired Using a MIZ30 Eddy Current Instrument Operating with a Gain of "×2" and a Drive Voltage of 12 Volts-PP)

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Figure 3-28
"Raw" (Not Normalized) 300 kHz Signal from a Rotating Plus-Point Detecting a 100% Deep Circumferential EDM Notch in an Inconel 600 Calibration Tube Used in Data Acquired with a Qualified Technique in Accordance with ETSS 21998. This Signal was Acquired Using a MIZ30 Eddy Current Instrument Operating with a Gain of "×2" and a Drive Voltage of 12 Volts-PP)

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Figure 3-29
Normalized 300 kHz Signal from a Rotating Plus-Point Probe Detecting a 40% Deep OD Axial EDM Notch in an Inconel 600 Calibration Tube Used in Data Acquired with a Qualified Technique in Accordance with ETSS 21998. This Signal has been Normalized by Setting the Peak-to-Peak Phase of the 40% Deep ID Axial EDM Notch Signal to 15 Degrees and Setting the Voltage of the Signal from the 100% Deep Axial EDM Notch to 20 Volts-PP)

3.4 Array Probe (X-Probe) Comparisons

The capability of a new proposed technique to generate equivalent or larger (not normalized) flaw signal should be demonstrated using signals from a 100% deep, 0.375" (9.525 mm) long axial EDM notch. If the array probe uses different groups of coils for detecting axial and circumferential flaws, then the capability of a proposed to generate signals from circumferential flaws of equal or greater amplitude as generated by a qualified technique should be evaluated using a 100% deep, 0.375" (9.525 mm) long circumferential EDM notch.

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The capability of a new proposed technique to generate equivalent signals (amplitude and phase) on a comprehensive set of flaws should be demonstrated using the 40, 60 and 100% deep axial and circumferential EDM notches in Tube 2, or in Tubes 3 and 4. 20% deep EDM notches are often too small to generate clear repetitive signals for demonstrating equivalency.

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These tolerances allow for signal variances that can occur due to tolerances in machined flaw dimensions and typical variations in tube wall thickness, as well as tolerances in eddy current probe dimensions, probe centering and array coil coverage. These tolerances are within observed variances generated by fully qualified array probe techniques.

X-Probes qualified in accordance to ETSS 20400, 20403 and 20502 used a 3x16 pancake coil arrangement in 0.75" (19.05 mm) diameter Inconel 600 tubing with nominal wall thickness of 0.043" (1.092 mm). The X-Probe designed for the 0.625" (15.875 mm) diameter Inconel 690 replacement SG tubing was a 2x14 pancake coil arrangement. The fewer coils used in the smaller SG tubing were chosen so that each of the transmit-receive coil pairs had equivalent center-to-center spacing as the corresponding coil pairs in the probe design that was qualified for the larger diameter tubing.

Essential variables for data acquisition using techniques ETSS 20400, 20403 and 20502 are identical. The only differences between these techniques are the various flaw mechanisms that each technique was qualified to detect. Therefore, a comparison of the calibration EDM notch flaws from the X-Probe technique used with the comparable notch signals from any of the qualified techniques should provide the evidence required to establish equivalence between the X-Probe technique and the three qualified techniques.

A listing of the differences in essential variables between the qualified ETSS's and the X-Probe technique deployed in replacement SG tubes is listed in Table 3-17.

Calibration tube data from the Qualified X-Probe techniques was procured from the EPRI qualification data. Calibration tube data from the replacement SG technique was acquired at an inspection of the unit with the replaced SG's.

The "raw" (with tube header setup) voltage reading from the 100% deep axial notch from the qualified probe at 300 kHz was 305 Volts pp where the same signal in the SG cal tube was 424 Volts pp from the axially aligned X-Probe transmit-receive coils.

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Both sets of readings were performed using Eddynet software. Both probes were driven with 48 db gain on the instrument. The tabulated "raw" signals are shown in Figures 3-30 to 3-33.

Table 3-18 is a summary of the comparison of normalized signals from calibration EDM notches acquired from scans using the qualified techniques, and the X-Probe technique used in the replacement SG tubes. Because the signal amplitudes were normalized differently, the signals from the replacement SG technique were re-scaled to values they would have if they were normalized to 2 Volts-pp from a 20% deep OD groove in accordance with the qualified X-Probe techniques. The differences ("errors") were smaller than the allowable tolerances documented in the proposed process for demonstrating technique equivalency documented in EPRI report number 1015126 [2]. A 380 kHz X-Probe signal from a 40% deep axial EDM notch in a calibration tube used is shown in Figure 3-34. For comparison, a corresponding 300 kHz X-Probe signal from a 40% deep axial EDM notch in a calibration tube used by techniques qualified in accordance with ETSS 20400.1, 20403.1 and 20502.1 is shown in Figure 3-35.

The signal comparisons between the techniques have passed the "raw" voltage criteria, and the normalized signal criteria documented in EPRI report number 1015126 [2], so this X-Probe technique deployed in these replacement SG tubes can be considered equivalent to the qualified techniques (ETSS's 20400.1, 20403.1 and 20502.1) according to this proposed equivalency demonstration process.

Table 3-17
Comparison of Peak-to-Peak Voltage Measurements from 100% Deep Axial and Circumferential EDM Notches from Calibration Tubes Used at the Unit with the Replaced SG's, and from Techniques Considered Qualified in Accordance with ETSS 21998.1

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ETSS #:20400.1, 20403.1 and 20502.1 (R5, Aug. 2006)

Table 3-18
Comparison of EDM Notch Signal Measurements for X-Probe Calibration Tube Scans at 380 kHz with 300 kHz Calibration Tube Data Acquired at EPRI Used to Qualify the X-Probe for Flaw Mechanisms Documented in ETSS 20400, 20403 and 20502

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Figure 3-30
"Raw" (Not Normalized) 380 kHz Signal from a X-Probe Detecting a 100% Deep Axial EDM Notch in an Inconel 690 Calibration Tube Used in Data Acquired from the Unit with the Replaced SG's (Signal was Acquired Using a TC7700 Eddy Current Instrument Operating with a Gain of 48 dB and a Drive Voltage of 2.5 Volts-P)

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Figure 3-31
"Raw" (Not Normalized) 380 kHz Signal from a X-Probe Detecting a 100% Deep Circumferential EDM Notch in an Inconel 690 Calibration Tube Used in Data Acquired from the Unit with the Replaced SG's (Signal was Acquired Using a TC7700 Eddy Current Instrument Operating with a Gain of 48 dB and a Drive Voltage of 2.5 Volts-P)

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Figure 3-32
"Raw" (Not Normalized) 300 kHz Signal from a X-Probe Detecting a 100% Deep Axial EDM Notch in an Inconel 600 Calibration Tube Used in Data Acquired with a Qualified Technique in Accordance with ETSS 20400.1, 20403.1 and 20502.1 (Signal was Acquired Using a TC7700 Eddy Current Instrument Operating with a Gain of 48 dB and a Drive Voltage of 2.5 Volts-P)

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Figure 3-33
"Raw" (Not Normalized) 300 kHz Signal from a X-Probe Detecting a 100% Deep Circumferential EDM Notch in an Inconel 600 Calibration Tube Used in Data Acquired with a Qualified Technique in Accordance with ETSS 20400.1, 20403.1 and 20502.1 (Signal was Acquired Using a TC7700 Eddy Current Instrument Operating with a Gain of 48 dB and a Drive Voltage of 2.5 Volts-P)

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Figure 3-34
Normalized 380 kHz Signal from an X-Probe Detecting a 40% Deep OD Axial EDM Notch in an Inconel 690 Calibration Tube Used (Signal has been Normalized by Setting the Phase of the Rolled Expansion Signal to 0 Degrees and Setting the Voltage of the Signal from the 30% Deep OD Groove to 5 Volts-PP)

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Figure 3-35
Normalized 300 kHz Signal from an X-Probe Detecting a 40% Deep OD Axial EDM Notch in an Inconel 600 Calibration Tube Used in Data Acquired with a Qualified Technique in Accordance with ETSS 20400.1, 20403.1 and 20502.1 (Signal has been Normalized by Setting the Phase of the Rolled Expansion Signal to 0 Degrees and Setting the Voltage of the Signal from the 20% Deep OD Groove to 2 Volts-PP)

3.5 Results

The results of this study indicate that, according to the proposed equivalency demonstration process in EPRI report 1015126, the techniques deployed in the replacement once through steam generator (SG) tubes could be considered equivalent to all of the qualified techniques listed except for the rotating plus-point technique ETSS 21998. A frequency of about 450 kHz is recommended to operate a plus-point probe in the thinner, higher resistivity steam generator tubes in an equivalent manner as the 300 kHz qualified channel used in ETSS 21998 if there is a desire to do so.

4
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ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Electric Power Research Institute (EPRI)

蒸気発生器管理プログラム：
検査技術の同等性を決定するための標準プロセスの開発

1018557

技術アップデート、2009年３月

EPRIプロジェクトマネージャ

T. Bipes

製品説明

電力会社は、原子力発電プラントの蒸気発生器（SG）管に対して渦電流テストを行うとき、認定された正規の技術を用いる。「認定された正規の」系統にある構成部品を交換するとき、元の認定系統との同等性を確認しなければならない。本報告書は、電力研究所（EPRI）の現在進行中の多年にわたるプロジェクトの中間的結果を説明するものである。同プロジェクトには、渦電流技術と、代替構成部品の同等性を決定する簡略なコスト効果のある方法の開発が含まれている。

EPRIのPWR蒸気発生器検査指針は、検査技術仕様シート（ETSS）が、機器、技術、解析のための本質的変項を定義すること求めている。ETSSで識別された範囲内で変化する本質的変項を持つ検査技術が、同等と見なされる。

非破壊検査（NDE）における技術や機器の進歩を活用するために、電力会社は、実施する前に技術や系統構成部品の同等性を実証しなければならない。これまでの慣例では、個々の電力会社が検査組織に対して、技術基盤を発展させることと、技術や代替構成部品の同等性を実証するのに必要な文書をそろえることを、検査サービスの一部として要求してきた。同等性を文書化するために現在実行されている複雑なプロセスは、結果として関係する電力会社にとってコスト増加となっている。検査技術の同等性を決定するための簡略かつコスト効果のあるプロセスがあれば、電力会社にとって財務上の利益になる。

結果と結論

本プロジェクトの前回の報告書（EPRI報告書１０１５１２６、検査技術の同等性を決定するためのプロセスの開発）において、提案された方法が、次の２つの間の同等性を実証するために文書化された。EPRIが認定したSG管の渦電流検査技術と、改良した本質的変項を持つ類似の検査技術の２つについてである。同等性実証には、２つの構成要素が必要である。一つの構成要素は、工学的技術正当化である。これは、本質的変項における変化が、SG管の欠点を検出し特性化する技術の実績に影響を与えない理由を説明する。もう一つの構成要素は、実際的な実証である。これは、改良された技術が、認定された技術と同等な信号を選択された校正用管の欠点から生成できることを示すものである。

本報告書は、改良された本質的変項を持つ現場技術と比較したいろいろなEPRI認定技術のレビューを文書化したものである。本質的変項の許容範囲の変化が、結果として渦電流信号に持つ影響も文書化されている。

問題点と目的

本報告書は、SGプログラムオーナーにとって有益な情報を提供すると共に、NDE専門家が、改良した本質的変項を持つ敷地検査技術用の妥当性確認文書を作成するのを支援する情報も提供する。継続している研究は今後、提案された同等性技術の実使用と、本質的変項への変更が渦電流信号に結果として与える影響に関する詳しい文書を提供するだろう。このプロジェクトの持つ利益には次が含まれる。１）系統の実績、技術実績、代替構成部品の同等性を評価する一貫したコスト効果のある方法を提供すること、２）いろいろなSG渦電流検査技術に関する同等性文書をそろえること。

EPRIの考え方

SG渦電流技術の同等性に関する決定は、複雑かつ費用の掛かるプロセスである。渦電流技術と代替構成部品の同等性を決定するための標準化された効率良いプロセスを開発することで、電力会社はコストを節減することができ、同等性の決定は短期間でできるようになる。

方法

調査員は、本質的変項が元のETSSに定義されている本質的変項の範囲外になる可能性がある新しい技術の同等性を文書化するため、計画書を作成した。当該技術、個々の系統構成部品、解析のための本質的変項の測定と合格基準が、EPRIの蒸気発生器検査指針に従って考慮されることとなった。

調査員は、電力会社のエンジニアまたはメーカ組織が同一の検査系統を準備できるようなプロセスを開発した。これは、現場で使えるように計画されたもので、エンジニアまたはメーカは、校正用標準欠点またはマスターサンプルを試験し、直ちにその系統が現在認定されている系統に対して「同等」かを見極めることができる。系統実績は、個々の系統要素を評価するよりも、全体として評価される。一貫した渦電流結果を得るために、系統実績評価を標準化する方法が開発された。

最終段階で、調査員は、検査技術の同等性を確認するために使える欠点を持つ管サンプルのマスターセットを設計· 生産した。検査技術の同等性を実証するため、マスターサンプルを使う手順が作成された。

キーワード

蒸気発生器
本質的変項
渦電流検査
検査技術仕様シート（ETSS）

目次

증기 발생기 관리 프로그램: 검사 기법 동등성 판정을 위한 표준 프로세스의 개발

1018557

기술 업데이트, 2009년 3월

EPRI 프로젝트 관리자

T. Bipes

제품 설명

전력 회사들은 원자력 발전소 증기 발생기(SG) 튜브에 대한 와전류 검사를 실시할 때 검증된 기법을 사용한다. "검증된" 시스템의 구성요소들이 바뀌면 최초에 검증된 시스템에 대한 동등성을 검증해야 한다. 이 보고서는 EPRI(Electric Power Research Institute)의 현재 진행 중인 다년간 프로젝트의 중간 결과를 설명한다. 이 프로젝트에는 단순하고 비용 효율적인 와류 기법 및 대체 구성요소의 동등성 결정 방법의 개발이 포함되어 있다.

EPRI PWR 증기 발생기 검사 지침에 따라 검사 기법 규격서(ETSS)에 장비, 기법 및 분석을 위한 필수적인 변수들을 정의하여야 한다. 필수적인 변수들이 ETSS에 확인된 범위 내에서 변화하는 검사 기법들은 동등한 것으로 간주된다.

비파괴 검사(NDE) 기법 및 장비 기술의 발전으로 생긴 이점을 누리기 위하여, 전력 회사들은 기법이나 시스템을 구현하기 전에 구성요소 동등성을 입증해야 한다. 지금까지의 관습은 각 개별 전력 회사가 검사 서비스 계약에 따라 검사 기관에게 기술이나 대체 구성요소 동등성을 입증하는 기술적 근거를 개발하고 필요한 문서를 작성하도록 요구하는 것이다. 동등성을 문서화하기 위해 현재 수행되는 정교한 프로세스는 관련 전력 회사들의 비용을 증가시켰다. 검사 기법 동등성의 판정을 위한 단순하고 비용 효과적인 프로세스를 통하여 전력 회사들은 재정적인 이익을 볼 수 있다.

연구 결과 및 소견

본 프로젝트의 이전 보고서(EPRI 보고서 1015126, *검사 기법 동등성 판정 프로세스의 개발*)에서 제안된 방법은 EPRI의 검증을 받은 SG 튜브에 대한 와류 검사 기법과 필수 변수들을 수정한 유사한 검사 기법 간의 동등성을 입증하기 위해 문서화된 방법이었다. 동등성 입증에는 두 가지 구성요소가 필요하다. 한 가지 요소는 필수 변수들의 변화가 SG 튜브의 결함을 탐지하고 그 특성을 기술하는 데 있어서 기법의 성능에 영향을 미치지 않는 이유를 설명하는 공학 기술적 정당성을 증명하는 것이다. 또 다른 요소는 수정된 기법이 선택된 캘리브레이션 튜브 결함에 기인한 신호로서 검증된 기법과 동등한 신호를 생성할 수 있음을 보여주는 실제적인 입증이다.

이 보고서에서는 필수 변수들이 수정된 현장 기법들과 비교하여 다양한 EPRI 검증 기법들을 검토한다. 또한 필수 변수 공차의 변경이 결과적인 와류 신호에 미치는 영향도 기록되어 있다.

과제 및 목표

이 보고서는 SG 프로그램 소유자와 지원하는 NDE 전문가에게 필수 변수들이 수정된 현장 검사 기법에 대한 검증 문서 개발에 유용한 정보를 제공한다. 계속되는 연구를 통하여 제안된 동등성 기법의 실제적인 이용과 와전류 신호에 대한 필수 변수 변경의 효과에 대한 문서를 추가로 제공할 것이다. 이 프로젝트의 이점은 1) 시스템 성능, 기법 성능 및 대체 구성요소 동등성을 평가하는 일관되고 비용 효율적인 방법을 제공하는 것과 2) 다양한 SG 와전류 검사 기법에 대한 동등성 문서를 체계적으로 작성하는 것이다.

EPRI의 관점

SG 와전류 기법 동등성의 판정은 복잡하고 많은 비용이 드는 프로세스였다. 와전류 기법과 대체 구성요소 동등성을 판정하는 표준화되고 효율적인 프로세스의 개발을 통하여 전력 회사들은 비용 절감의 이점을 누리고 훨씬 짧은 기간 내에 동등성 판정을 할 수 있도록 하여야 한다.

접근방법

연구자들은 새로운 검사 기법에 대한 동등성 기록을 위한 계획서를 작성했다. 이 계획서 내의 필수 변수들은 최초 ETSS에 정의된 범위를 벗어날 수도 있다. 기법, 개별 시스템 구성요소 및 분석을 위한 필수 변수들의 측정과 수용은 EPRI의 증기 발생기 검사 지침서에 따라 검토해야 한다.

연구자들은 전력 회사의 엔지니어 또는 납품업체의연구부서가 현장에서 사용하도록 계획된 것으로서, 동일한 검사 시스템을 정착시킬 수 있고, 교정 기준 결함 또는 마스터 샘플을 검사하고, 그 시스템이 검증된 현 시스템과 "동등"한지의 여부를 즉시 판정할 수 있는 프로세스를 개발했다. 시스템 성능은 개별 시스템 요소들을 각각 평가하지 않고 전체적으로 평가한다. 일관된 와전류 결과를 달성하기 위해 시스템 성능의 평가를 표준화하는 방법을 개발하였다.

마지막 단계에서 연구자들은 검사 기법 동등성 검사를 수행할 때 사용할 수 있는 결함이 있는 튜브 샘플의 마스터 세트를 설계하고 제작했다. 마스터 샘플을 사용해서 검사 기법 동등성을 입증할 수 있는 절차를 개발하였다.

키워드

증기 발생기

필수 변수들

와전류 검사

검사 기법 규격서(ETSS)

목 차

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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com