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GE NOZZLE MODELING

FOR THE ASSESSMENT OF

UT EXAMINATION TECHNIQUES

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ABSTRACT

Normally, ultrasonic (UT) techniques are qualified on test specimens of similar size and configuration as the component to be examined. In the Boiling Water Reactor (BWR) fleet, there are numerous configurations of nozzle geometry's with limited mockups available. With limited mockups available, alternate means are needed to evaluate UT methods in complex nozzle geometry's.

The GE Nozzle Modeling techniques support the design, the evaluation of UT methods, and the preparation of coverage maps for the ultrasonic inspection of BWR nozzle inside surfaces. The technique makes use of ray tracing algorithms to predict beam paths and incidence angles on the nozzle inside diameter (ID) surfaces. By determining acceptable incidence angles from actual mockup data, techniques are available to evaluate UT methods on other nozzle configurations.

This report describes the GE Nozzle Modeling methodology and summarizes the UT data acquired from nozzle mockups to support the use of modeling to evaluate nozzle UT techniques with the GERIS 2000 UT Imaging System.

INTRODUCTION

The geometry's of nozzles are complex. To perform ultrasonic (UT) examinations of the inside diameter (ID) surfaces from the outside diameter (OD), multiple UT methods are required. The nozzle-inner radius and bore are divided into regions identified as Zones. Figure 1 shows a cross-sectional view of a nozzle that identifies the inspection zones of the ID surfaces.

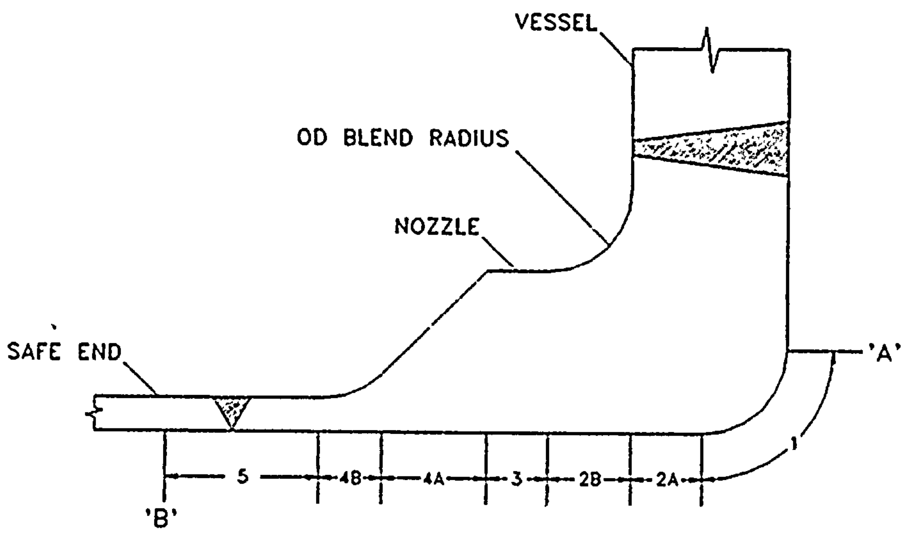

Figure 1 - Nozzle Examination Zones

The area requiring examination depends on the inspection requirement. For example, the ASME Boiler and Pressure Vessel Code, Section XI requires the examination of Zones 1 and 2A; while the Nuclear Regulatory Commission (NRC) NUREG-0619 requires full examination of Zones 1 through 5.

Transducer wedges are designed to meet the individual nozzle geometry requirements to produce a beam that is near to normal to a postulated radial oriented flaw. For example, depending on nozzle geometry, Zone 1 could be better examined from the nozzle OD blend radius verses from the vessel wall and vice versa.

The effectiveness of the examination techniques have been previously demonstrated on full-scale nozzle mockups (Reference 1). The results of the mock-up tests are correlated with the modeling process to form a basis of extending data taken from one nozzle to another.

With the aid of nozzle modeling, an assessment can be made of the designed wedge parameters for a different nozzle to determine:

1) the scan coverage; and

2) the normality of the beam to a postulated radial flaw.

The use of nozzle modeling has improved the methods for assessing nozzle examination techniques. This has resulted in increased examination reliability which assure that nozzle integrity is more effectively assessed.

SUMMARY

GE's Nozzle Modeling techniques serve as the basis for the design and evaluation of nozzle examination techniques. Qualification data collected with the GERIS-2000 system documented in this report illustrates the detection capabilities as a function of the relationship of UT sound beams to flaws. With acceptable misorientation angle limits, computer modeling can be applied to other nozzle configurations to demonstrate that proposed techniques are within the acceptable bounds.

The information presented in this report shows the usefulness of the GE Nozzle Modeling process. The GE Nozzle Modeling process provides both a qualitative and quantitative means of evaluating UT methods without having to perform multiple mockup qualification tests.

GE NOZZLE MODELING

The GE Nozzle Modeling techniques use geometrical ray tracing algorithms to predict beam paths and incidence angles on the ID surfaces. The detection of opposite surface flaws with UT is a complicated, which cannot be treated by a direct application of geometrical ray tracing. Due to this fact, certain limitations are placed on the incident beam conditions.

The amplitude response from a defect is affected by the incident angles at which the beam strikes the flaw. The two angles that are used to define the beam direction are termed alpha (a) and beta (b), as illustrated in Figure 2. Alpha is the incident angle on the flaw, and is the angle between the beam and the transverse axis of the flaw. For specular reflection, the alpha angle is 90°, and is where the sound waves are reflected directly back from the face of the flaw. For a corner trap, the alpha angle is close to 45°, and is where the sound waves are reflected off of two surfaces (a flaw and the ID surface) before returning to the transducer.

The other angle, beta, is the angle between the normal axis of the flaw and a projection of the beam onto the plane formed by the longitudinal and normal axis of the flaw. The beta angle is commonly referred to as the *misorientation angle.*

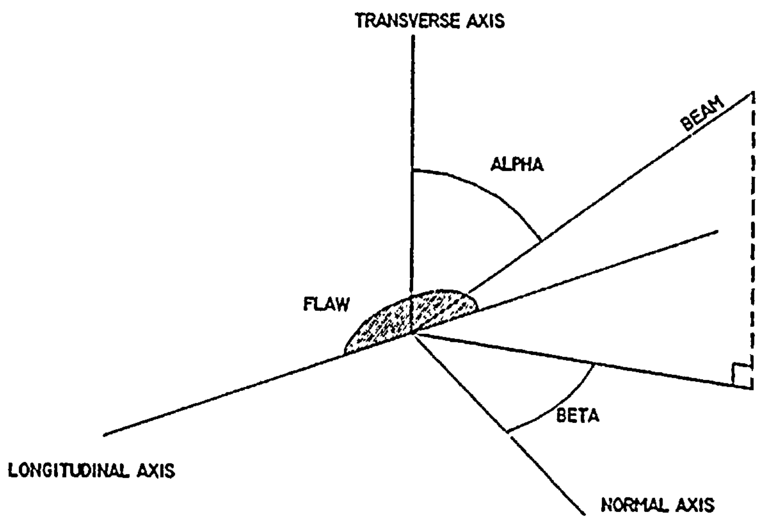

Figure 2 - Definition of Alpha and Beta at a Defect

The alpha and beta angle limitations are determined from previously collected nozzle mockup data. The data was collected with the GERIS 2000 Ultrasonic Imaging system. The mockup contains notches that are located throughout the inner-radius and bore regions The Section titled "Mockup Descriptions" describes and illustrates the mockup and notches.

Multiple inspection methods were used to collect UT data in determining acceptable incident beam angles on the ID surface. The different methods included: 1) various alpha and beta angles; and 2) the surface from which the scanning is performed.

The beam and rotation angles, and scan paths that were used to collect the UT data were analyzed with the nozzle modeling process. The process consists of projecting beam vectors from the OD scanning surface to the ID surface. The projection of the sound beam is performed throughout the entire scan path on the OD surface (both radial and circumferential scan axes). At the location that the beam intersects the ID surface, the alpha and beta angles are determined. These data points are superimposed on a rollout map of the ID surface containing notch locations.

The values in the rollout can represent either the alpha or beta angle values and are positioned at the location that the beam intersected the ID surface. Also in the rollout view are the locations of the notches. In the cross-sectional view, the lines from the OD surface to ID surface represents a plotted beam at the 270° (top) location of the nozzle. The cross-sectional beam plot is performed once for each radial location.

As a visual aid the alpha or beta angle values and cross-sectional beam plots are color coded to reflect the beta (misorientation) angle (i.e., 0-10 red; 11-20 green; 21-30 cyan; 31-40 blue; and equal to or greater-than 41 black).

The amplitude responses from the notches are determined through the aid of the recorded RF data and the processed images. The images created by the GERIS 2000 provide flaw identification, and the A-scan display provides the amplitude information.

TEST RESULTS

Multiple UT scans were performed using the GERIS-2000 Ultrasonic Imaging System. This data is used to qualify the nozzle-inner radius detection capabilities and also to determine the alpha and beta limits. Table 1 for the unclad nozzle and Table 2 for the clad nozzle illustrates the examination scans that were used to determine the limits used in modeling.

DP1 FEEDWATER NOZZLE EXAMINATIONS			
TYPE	EXAM ZONE	EXAM SURFACE	ANGLE ON ID (ALPHA)
Z1V	1	VESSEL	58°
Z1R	1	NOZZLE RADIUS	45°
Z2R45	2A,2B	NOZZLE RADIUS	45°
Z2R60	2A,2B	NOZZLE RADIUS	60°
Z2Q	2A	NOZZLE FLAT	72°
Z2M	2A	NOZZLE FLAT	70°
Z2T	2B	NOZZLE FLAT	70°
Z3	Z3	NOZZLE FLAT	45°
Z4A	Z4A	NOZZLE TAPER	45°
Z4T	Z4A	NOZZLE TAPER	60°

Table 1 - Unclad Nozzle Examination Parameters

CE4 FEEDWATER NOZZLE EXAMINATIONS			
TYPE	EXAM ZONE	EXAM SURFACE	ANGLE ON ID (ALPHA)
Z1V	1	VESSEL	47°
Z1V	1	VESSEL	59°
Z1V	1	VESSEL	73°
Z1R	1	NOZZLE RADIUS	45°
Z2R45	2A	NOZZLE RADIUS	45°
Z2R60	2A	NOZZLE RADIUS	60°

Table 2 - Clad Nozzle Examination Parameters

MOCKUP DESCRIPTION

CLAD REMOVED FEEDWATER MOCKUP (EDM NOTCHES)

The clad removed feedwater nozzle mock-up used in the qualification testing was fabricated by GE of components from a canceled BWR manufactured under Chicago Bridge & Iron - Nuclear (CBIN) contract number 72-2505. The nozzle forging was a flanged and clad recirculation inlet nozzle with a material specification of SA 508 Class 2. The nozzle was welded into a vessel plate from shell course #1 with material specifications of SA 533 Grade B, Class 1.

The forging was machined to represent a barrel-type feedwater nozzle that had the clad removed. The scanning for Zone 2A was performed on the nozzle-to-vessel weld surface. This surface was hand welded and ground. This is typical of the nozzles that experienced nozzle-inner-radius cracking in the field. This nozzle-to-vessel weld configuration was selected because scanning from hand-ground surfaces is the most difficult.

UNCLAD FEEDWATER NOZZLE MOCKUP (FATIGUE CRACK IMPLANTS)

To confirm the detection and sizing of fatigue cracking, two fatigue crack implants were welded into an unclad feedwater nozzle forging. The unclad feedwater nozzle mockup used for implanting these fatigue cracks is from a canceled BWR. This feedwater nozzle came from a RPV that was originally fabricated by CBIN under contract number 74-C131. The nozzle forging is flanged and unclad with a material specification of SA 508 Class 2. The nozzle is welded into a vessel plate with material specifications of SA 533 Grade B, Class 1.

The fatigue cracks were generated in SA 508 Class 2 material specimens. The specimens were machined into an implant with dimensions of approximately 1.3" long by 0.38" wide by 0.49" deep with the fatigue crack in the center. Cavities were machined in the nozzle inner-radius where the cracked specimens were implanted using the gas tungsten arc (GTA) and shielded metal arc (SMA) welding processes using narrow width joint designs. The temperature of the inner-radius was maintained between 150 to 350 degrees during the implant welding process. The Post-weld heat treatment consisted of heating the inner-radius to a temperature of 1150 degrees with a soak-time of 1 hour.

CLAD FEEDWATER MOCKUP (NOTCHES AND CRACKS)

The clad feedwater nozzle mockup used for demonstrating detection and sizing is from a canceled BWR. This feedwater nozzle came from an RPV that was originally fabricated by CE (Combustion Engineering). The nozzle forging is flanged and clad with a material specification of SA 508 Class 2. The nozzle is welded into a plate with material specifications of SA 533 Grade B, Class 1.

The fatigue cracks are generated by the process called mechanical-fatigue-crack implanting. Cavities are machined in the nozzle inner-radius and bore where the cracked is to be located. One face of the cavity is the same axis as the intended crack. A tension bar is then attached to this face using the gas tungsten arc (GTA) welding processes. A starter notch is made at the site of the fatigue crack in the base material. The breaker bar is then low-cycled fatigued until the breaker bar separates, thus creating the one face of the crack implant. The other face of the implant remains in the cavity. The face of the crack is then machined from the breaker bar and positioned to match the crack face in the cavity. The crack implant is then seal welded and the cavity is then filled up with GTA weld material.

GERIS 2000 ULTRASONIC IMAGING SYSTEM

The Ultrasonic subsystem has a multiplexed logarithmic UT flaw detection instrument. For each channel, the complete RF A-scan is digitized and stored on optical disks. The system stores the RF signal in logarithmic format that has an instantaneous dynamic range greater than 85 dB. This allows the recording of the peaks of low and high amplitude UT signals at the same time with out clipping UT signals, such as would occur with linear systems that have an instantaneous dynamic range generally less than 45 dB.

The system can record a complete set of RF waveforms from as many as 16 channels concurrently while scanning at 2.0 inches (51 mm) per second and taking data every 0.15 inches (3.8 mm). The pulse sequence for each of the channels is controlled by the Hewlett Packard (HP) 730 workstation. Each channel is equipped with adjustable gate length to accommodate various types of angle-beam examination conditions. The system stores all RF data in raw form and, if necessary, the data is distance-amplitude-corrected (DAC) through software. The original RF data file is never altered. The A- and C-scans are displayed during calibration and data acquisition.

The GERIS 2000 analysis system utilizes advanced interactive color graphics to evaluate and assist in characterizing indications from service induced, fabrication and geometry related UT reflectors. Coordinated A-, B-, C-, volumetric side-view-, volumetric end-view- and 3D-scans are provided on a high resolution (1280 by 1024 pixels) color display. Several channels of these scans may be displayed at one time. These graphic displays have an adjustable color scale that provides the best resolution of flaw detection and characterization down to the material noise. The presentation of the data can be readily changed from or to gray scale.

Real-time interaction between all displayed views (of a given scan) is automatic and provides analysis personnel with quick coordination and identification of data.

REFERENCES

1) GE-NE-A00-05452, GE Proprietary, "GERIS 2000 Ultrasonic Inspection of Feedwater Nozzles", GE Nuclear Energy, January 1, 1996.