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January 12, 2008

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Subject: Final Report of the Nondestructive Evaluation (NDE) and Engineering Analysis of Jacksonville Electric Authority (JEA) Northside Generating Station Combustion Turbine Unit 5 (NSCT5) Generator Rotor.

Reference: NAES PO# 07-1786
R&A C-7368

Dear Dominic,

Reinhart and Associates, Inc. (R&A) is pleased to submit the final report of the nondestructive examinations and engineering analysis of the JEA NSCT5 generator rotor.

R&A looks forward to the opportunity to work with *NAES* again in the future. If you have any questions or need further assistance, please call.

Sincerely,

____

Teodoro Leon-Salamanca, Ph.D.
Director of Engineering

FINAL REPORT
BORESIDE NONDESTRUCTIVE EXAMINATIONS & ENGINEERING ANALYSIS
JACKSONVILLE ELECTRIC AUTHORITY
NORTH SIDE COMBUSTION TURBINE U-5
GENERATOR ROTOR

NORTH AMERICAN ENERGY SERVICES
PO# 07-1786 / R&A C-7293
November 5, 2007

Submitted to:

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EXECUTIVE SUMMARY

Reinhart & Associates, Inc. (R&A), performed nondestructive examinations (NDE) on the Jacksonville Electric Authority (JEA) North Side Combustion Turbine U-5 (NSCT5) generator rotor for North American Energy Services during the period of October 31 to November 5, 2007. The JEA NSCT5 generator rotor was manufactured by General Electric. The NDE examinations performed consisted of visual (VT) and wet fluorescent magnetic particle (WFMT) of the bore surface and ultrasonic examination (UT) from the rotor boreside. Because service stress is highest at the bore surface, all of the examinations concentrated on this region. The NDE examinations were performed to provide information on the current condition of the rotor. An engineering analysis was then conducted using the examination results to provide information on the suitability for future service. In addition to the boreside NDE, eddy current testing (ET) was performed on the generator rotor teeth and wedging and penetrant testing (PT) performed on the generator retaining rings.

SUMMARY OF EXAMINATION RESULTS (2007)

The results of the JEA NSCT5 generator rotor BORESIDE NDE examinations of November 2007 performed by R&A personnel are listed below.

ROTOR	Boreside VT	Boreside WFMT	Boreside UT
GENERATOR	NRI*	14 Areas of Linear RI	9,682 Data Points

* NRI = No Recordable Indications

The ET examination of the rotor body coil slot dovetails and wedges on slots 1, 12, 13, and 24 revealed no recordable indications.

The fluorescent PT of the inside diameter and outside diameter surface of the turbine and exciter end retaining rings revealed no recordable indications.

COMPARISON OF EXAMINATION RESULTS (2002 & 2007)

YEAR COMPANY	**Boreside VT**	**Boreside WFMT**	**Boreside UT**
2007 R&A	NRI*	14 RI	9,682 Data Points
2002 WDI	NRI	23 RI	1,332 Data Points
2002 GE	5 RI	54 RI	600 Data Points

* NRI = No Recordable Indications
R&A = Reinhart & Associates, Inc.
WDI = Wesdyne International, Inc.
GE = General Electric

The comparison between the results of the 2007 boreside examination performed by R&A personnel with the results of the 2002 boreside examinations performed by General Electric (GE) and Wesdyne International, Inc. (WDI) personnel show that the JEA NSCT5 generator rotor condition is basically unchanged.

The 2007 boreside VT examination performed by R&A personnel revealed no recordable indications as reported by WDI in 2002.

The 2007 boreside WFMT examination performed by R&A personnel revealed 14 areas of linear indication ranging in size of 0.030 inches to 0.125 inches in length. The reason the number of recordable indications changed from 2002 to 2007 is because power honing removes a few thousands of an inch off the boreside surface changing the map and number of surface connected indications (these indications are only a few thousands of an inch in radial depth).

The 2007 boreside UT examination performed by R&A personnel revealed 9,682 data points. The comparison of the UT data from this examination with the UT data collected in 2002 shows no change. The heavy concentration of data points ranged in Z from 165 inches to 200 inches from the turbine end. The number of UT data points increased because the R&A B-SURE® 3000 system used for the examination collects data at a much faster rate than the systems used in 2002.

SUMMARY OF ENGINEERING ANALYSES

The remaining start/stop cycles were calculated using the results of the NDE examinations, material properties obtained from previous reports, mechanical and thermal stress calculations based on normal operating conditions of the unit, and fracture mechanics analysis. The table below summarizes the results of the engineering analysis.

ROTOR	Bore Area	Stress Level	*a_{cr}	$2c_{cr}$	Number of Cycles
Generator	Main Body	54,000 psi	0.6873 in	2.7500 in	8,320

*Critical flaw size. Initial flaw size $\mathbf{a_i}$ = 0.150 in. and $\mathbf{2c_i}$ = 0.600 in.

SUMMARY OF RECOMMENDATIONS

Based on the results and engineering analysis of the 2007 boreside NDE examination performed in by Reinhart & Associates, Inc., it is recommended that the JEA Northside Station Unit 5 Generator rotor be reinspected within the next 10 years (87,600 hrs) of additional service. The recommended reinspection interval only considers the main shaft forging and does not consider any winding reinspection interval. The recommended rotor reinspection interval may not account for the occurrence of unusual conditions or any other event that could affect the integrity of the system. Such events include rotor unbalance, changes in vibration states during run-down or start-up, motoring of the generator, overspeeding, and major rotor repairs. Boreside nondestructive testing should be performed immediately after such occurrences.

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1. INTRODUCTION

1.1 Inspection Overview

Reinhart & Associates, Inc. (R&A), performed nondestructive examinations (NDE) on the Jacksonville Electric Authority (JEA) North Side Combustion Turbine U-5 (NSCT5) generator rotor for North American Energy Services during the period of October 31 to November 5, 2007. The JEA NSCT5 generator rotor was manufactured by General Electric, commissioned in 1974 and rated as 62 MW. The NDE examinations performed consisted of visual (VT) and wet fluorescent magnetic particle (WFMT) of the bore surface and ultrasonic examination (UT) from the rotor boreside. Because service stress is highest at the bore surface, all of the examinations concentrated on this region. The NDE examinations were performed to provide information on the current condition of the rotor. An engineering analysis was then conducted using the examination results to provide information on the suitability for future service. In addition to the boreside NDE, eddy current testing (ET) was performed on the generator rotor teeth and wedging and penetrant testing (PT) performed on the generator retaining rings.

2. DISCUSSION

2.1 Plug Removal and Surface Preparation

Prior to boreside nondestructive examinations one or both bore plugs are removed from the rotor to provide access to the bore surface. The bore surface is then prepared by using a power honing system to remove any surface irregularities that may form while the unit is in service. Pre- and post-hone boreside diametrical measurements are taken to document the amount of material removed during the honing process. Upon completion of the boresonic examination a newly manufactured bore plug is installed using Liquid Nitrogen to ensure proper interference fit.

2.2 Boreside NDE

2.2.1 Visual Examination

Boreside VT examination is performed to determine if the bore surface is suitable for NDE examination. A white light borescope is used to visually inspect for surface defects and any other discontinuities that could yield false indications during the other examinations. Once the bore surface is deemed suitable, the WFMT and UT examinations are performed.

2.2.2 Magnetic Particle Examination

There are two techniques used for boreside WFMT of rotors. The first WFMT examination technique utilizes a specially designed half-wave rectified AC (HWAC) electromagnetic yoke. This yoke produces a circumferential magnetic field in order to detect primarily axially oriented surface or slightly sub-surface discontinuities. The first technique is utilized most of the time and only requires the removal of one bore plug. The second technique utilizes a magnetic machine and a central conductor that produces a circumferential magnetic field to detect primarily axially oriented surface or slightly sub-surface discontinuities. The second technique may be utilized when the bore configuration contains a step or a bottle and both plugs are usually removed.

2.2.3 Ultrasonic Examination

The boreside UT examinations are conducted utilizing the R&A B-SURE® data acquisition system. This multiple channel system incorporates recording and data display capabilities into a real-time field ready system. The system is capable of capturing, correcting, and displaying data on the job site. Two ultrasonic scans are performed on each rotor. The boreside ultrasonic search unit carrier module is driven in a continuous helical scan with approximately 0.100 inches of advancement per revolution to provide maximum detectability. Table I lists the scans performed, UT search units, and sound paths utilized during the automated boreside examinations.

Table I. B-SURE® ultrasonic scans parameters.

SCAN SET	Transducer Type, Angle, Frequency, and Metal Path
Scan I	Radial scan, 0° longitudinal wave, 5 MHz, 0-2.5 in. radial depth
	CW circumferential scan, 45° shear wave, 2.25 MHz, 0-5 in. metal path
	AFT axial scan, 45° shear wave, 2.25 MHz, 0-5 in. metal path
Scan II	Radial scan, 0°longitudinal wave, 2.25 or 5 MHz, 0-10 in. radial depth
	CCW circumferential scan, 45°shear wave, 2.25 MHz, 0-5 in. metal path
	FWD axial scan, 45°shear wave, 2.25 MHz, 0-5 in. metal path

2.3 Engineering Analysis Approach

An engineering analysis of the rotor is performed to evaluate its current condition and suitability for future service. The region of greatest concern especially in a hollow rotor is at the surface of the bore, where the highest mechanical stresses exist during service. Due to the geometric nature of a bore, the hoop or circumferential stress (σ_h) as shown in Figure 1 becomes the dominant factor in a rotor analysis. It is the hoop stress that cyclically (one cycle = one start/stop) operates on a bore surface connected flaw causing it to propagate, eventually leading to rotor failure. Therefore, after determining the maximum hoop stresses in the rotor, the remaining life is calculated using the boreside nondestructive examinations (NDE) results, nominal or measured material properties of the rotor, and linear elastic fracture mechanics principles. The engineering analysis only considers the rotor main shaft and is based on the results from the following items:

2.3.1 Initial Flaw Size

Boreside NDE is performed following plug removal and honing of the bore surface. Honing is performed to provide an acceptable bore surface condition for NDE. The indications obtained from flaws during boreside NDE are analyzed using a link-up analysis program to determined their location, size, shape, number, and distribution. The axial length and angular location of surface connected flaws are obtained from visual tests (VT), wet fluorescent magnetic particle tests (WFMT), and/or eddy current tests (ET). The ultrasonic tests (UT) scans provide information on axial length, radial extent, and angular location of surface connected and embedded flaws. A bore surface connected flaw represents the most detrimental condition to the integrity of a hollow rotor, thus the results from boreside NDE are used to determine initial flaw size $\mathbf{a_i}$= radial depth and **2c** = axial length as shown in Figure 1. If no surface connected indications are detected, a default initial flaw size based on the examination system performance is assumed to have been missed during the examination. The ratio (a/2c) = 0.25 is typical of real fatigue flaws found in rotors as contained in the bore connected fatigue flaw set of the EPRI (Electric Power Research Institute) blocks RP-502 used for the B-SURE® system performance evaluation. The ratio (a/2c) = 0.25 means that the initial flaw is 4 times larger (axially) than it is deep (radially).

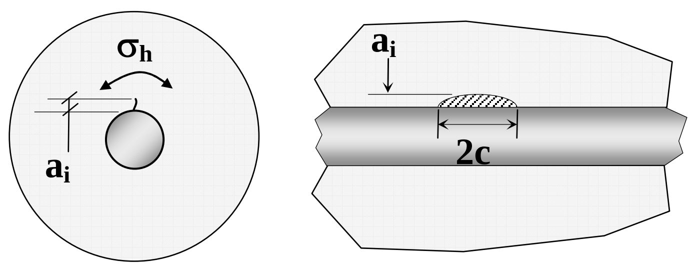

Figure 1. Hoop stress orientation and bore surface connected flaw initial dimensions determined by NDE.

2.3.2 Rotor Material Properties

The rotor material properties are obtained from the results of elemental analysis and alloy identification using rotor bore shaving material samples obtained during power honing of the bore surface. Other material samples can be removed to determine the rotor material properties these include, core samples, ring samples, sliver samples, bore miniature samples, periphery filing samples, etc. The alloy specification obtained form any of these samples is used to retrieve published material properties from ASTM standards such as, yielding stress (σ_y), ultimate tensile stress (UTS), modulus of elasticity (E), critical stress intensity factor (K_{IC}), fracture appearance transition temperature (FATT), fatigue crack growth rate (da/dn), etc. If material samples are not collected, then the nominal material properties used in the analysis are determined by using Client information, manufacturing date of the rotor, or the most typical material specification for the rotor type.

2.3.3 Mechanical & Thermal Stress

The rotor bore mechanical and thermal hoop stress (σ_h) results are calculated using published mathematical equations or a finite element stress analysis performed to determine the stress distribution especially near the bore surface. The mechanical stress is calculated using the information provided by the Client during start-stop cycles or by assuming that the rotor is operating at 3600 rpm. The transient thermal stress is generated by a temperature gradient that exists between the periphery of the rotor and the bore surface during the unit startup. If a finite element analysis is performed the Client must provide heat balance information to calculate thermal gradients. If a short form analysis is performed a typical temperature gradient is assumed for HP, IP, and HP-IP rotors, between 200°F and 250°F and for LP rotors between 100°F and 150°F. The steam temperature ramp rate used during start up is set to 3° F per minute.

2.3.4 Critical Flaw Size

Linear elastic fracture mechanics (LEFM) principles are used to calculate the number of start/stop cycles that will be expended to grow the initial flaw size $\mathbf{a_i}$ determined in item **2.3.1** above until it reaches the critical size $\mathbf{a_{cr}}$. The most serious condition that will affect the life of a hollow rotor is when a surface connected flaw oriented in the axial radial plane is located in the highest stressed area (hoop tensile stress) of the bore. Using the LEFM principles a stress intensity factor K_I for a bore surface connected flaw is calculated using the current flaw size and stress level. The K_I increases as the flaw size increases and/or as the tensile hoop stress increases. The calculated value of K_I is compared to the material property K_{IC} value obtained from **2.3.2** above. If the current stress intensity factor K_I is equal to or larger than the critical stress intensity factor K_{IC}, then the flaw will propagate quickly making the rotor unstable. Before this condition is met the flaw grows at a fatigue flaw growth rate (da/dn) until it reaches a critical flaw size $\mathbf{a_{cr}}$. Adding or integrating the number of times that this occurs will yield the total number of times that it will take the flaw to increase its size from $\mathbf{a_i}$ to $\mathbf{a_{cr}}$. Figure 2 shows the comparison between initial flaw size conditions determined by NDE and the critical flaw size conditions determined by LEFM.

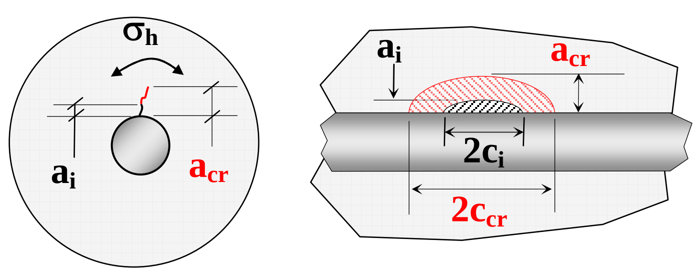

Figure 2. Bore surface connected flaw initial dimensions by NDE and critical dimensions by LEFM.

2.3.5 Reinspection Interval

Common industry practice on reinspection intervals vary from 5 to 10 years of additional service on rotors that do not present any serious condition. A reinspection interval is usually recommended depending on the results of the engineering analysis, engineering judgment, and known factors which include, but are not limited to:

Rotor boreside surface indications, i.e. visual, magnetic particle, eddy current, etc.
Rotor boreside subsurface indications, i.e. ultrasonic, link-up analysis, etc.
Rotor bore configuration, i.e. straight, step bore, bottle bore, etc.
Changes of operating conditions of the unit, i.e. from base load to peak load, etc.
Rotor background, i.e. previous examinations, overspeeding, material degradation, etc.
Rotor repairs, i.e. weld build-up repair, stub shaft replacement, etc.

The reinspection interval determined is used as a recommendation for a planned outage and it is based on a deterministic analysis for each rotor and it is not determined following a specific code or regulation. This reinspection interval only considers the main shaft forging and does not consider any blading reinspection interval.

The recommended rotor reinspection interval may not account for the occurrence of unusual conditions or any other event that could affect the integrity of the system. Such events include major blade loss, rotor unbalance, changes in vibration states during run-down or start-up, water ingestion, excessive temperature excursions, motoring of the generator, over speeding, and major rotor repairs. Boreside nondestructive testing should be performed immediately after such occurrences. Run, repair, or retire decisions are recommended based on the results of the analysis. However, the final disposition of a rotor is responsibility of the Client or Owner of the rotor.

3. EXAMINATION RESULTS

3.1 Plug Removal and Surface Preparation

Prior to boreside nondestructive examinations of the JEA NSCT5 generator rotor the governor or turbine end (TE) bore plug was removed and power honing was performed to provide a bore surface suitable for nondestructive examinations. The exciter end bore plug and copper bar were removed by others. Bore diameter measurements were taken before and after power honing. An average of 0.006 in. of material was removed during the honing process resulting in a nominal bore diameter of 3.007 inches. Bore dimensions after honing are shown in Figure 3. A replacement plug was fabricated and installed after all the NDE examinations were completed. The TE plug bore dimensions were measured as ID = 3.501 inches and length = 3.070 inches. The new plug has OD = 3.505 inches and length = 3.000 inches.

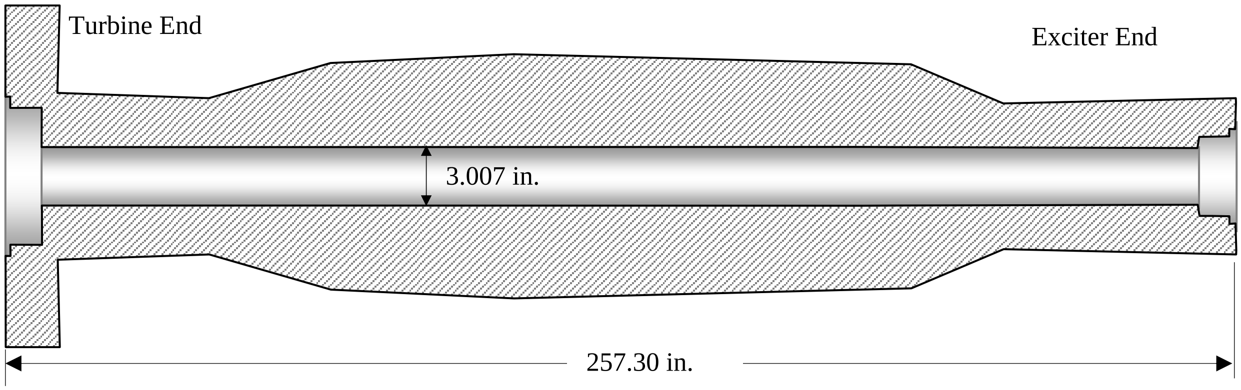

Figure 3. Sketch of JEA NSCT5 generator rotor bore configuration and dimensions (not to scale).

3.2 Boreside Visual Examination

A boreside visual examination (VT) of the JEA NSCT5 generator rotor was conducted upon completion of the honing. A white light borescope was used to visually inspect for surface defects and to determine if the surface was suitable for magnetic and ultrasonic testing.

The boreside VT examination revealed no recordable indications.

3.3 Boreside Magnetic Particle Examination

The boreside wet fluorescent magnetic particle examination (WFMT) of the JEA NSCT5 generator rotor was accomplished in two separate passes. The WFMT examination utilized a central conductor to produce a circumferential magnetic field in order to detect primarily axially oriented surface or slightly sub-surface discontinuities. The boreside WFMT examination revealed 14 areas of linear indication ranging in size of 0.030 inches to 0.125 inches in length as listed in Table II. The largest area of these indications was measured as 0.600 inches. Figure 4 shows a photo of one of the indications noted during the MT examination.

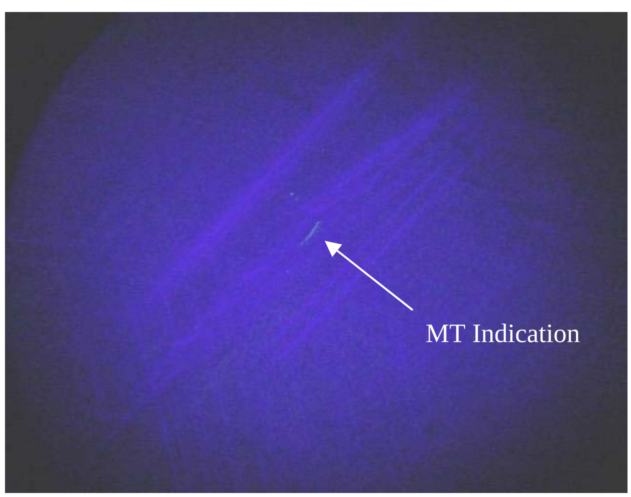

Figure 4. Photo of one of the WFMT indications observed on the JEA NSCT5 generator boreside.

Table II. List of WFMT indications detected during boreside NDE of JEA NSCT5 generator rotor.

Ind. No.	Axial Location (in)	Angular Location (deg)	Axial Extent* (in)
1	20.75	5	0.100
2	32.25	100	0.500
3	47 to 50	225	0.250
4	56.50	45	0.500
5	57.325	230	0.100
6	59.625	130	0.100
7	63.00	45	0.125
8	71.625	5	0.600
9	73.75	245	0.250
10	141.75	100	0.100
11	146.00	180	0.100
12	152.75	180	0.100
13	171.25	135	0.125
14	173.25	180	0.600

* Extent of groups of intermittent broken indications ranging in linear lengths of 0.030 to 0.125 inches.

3.4 Boreside Ultrasonic Examination

Boreside ultrasonic examination of the JEA NSCT5 generator rotor revealed a total of 9,682 data points from subsurface small point source reflectors. The circumferential (clockwise and counterclockwise) and axial (for and aft) shear wave scans are best suited for detecting a radially oriented discontinuity. Based upon the lack of "traveling" characteristics of the circumferential and axial shear wave scans, there is no evidence that a radial component exists near or at the bore surface.

Figure 5 shows a C-scan illustrating the location of all detected ultrasonic reflectors (9,682 data points) in the generator rotor defined by the angular position θ (degrees) and axial position Z (in) along the rotor from the turbine end. The color-coding corresponds to Equivalent Flat Bottom Hole (EFBH) diameter sizing of the ultrasonic reflectors as indicated by the color-coded bar located on the top right hand side of the figure. A B-scan shown in Figure 6 depicts the distribution of all detected ultrasonic reflectors in the generator rotor as a function of radial depth or metal path MP (in) from the bore surface along the axial length of the rotor Z (in) from the turbine end. Figure 7 shows a polar plot of all detected ultrasonic reflectors in the generator rotor defined by angular location θ (degrees) and radial depth R (in.) from the bore surface.

Attachment A includes a tab delimited Microsoft Excel® text file named “C-7368 ALLGENDATA.FBH” recorded on a CD that contains all the ultrasonic data (9,682 data points) listed in table form as radial depth, axial distance, angular position, and calculated EFBH diameter.

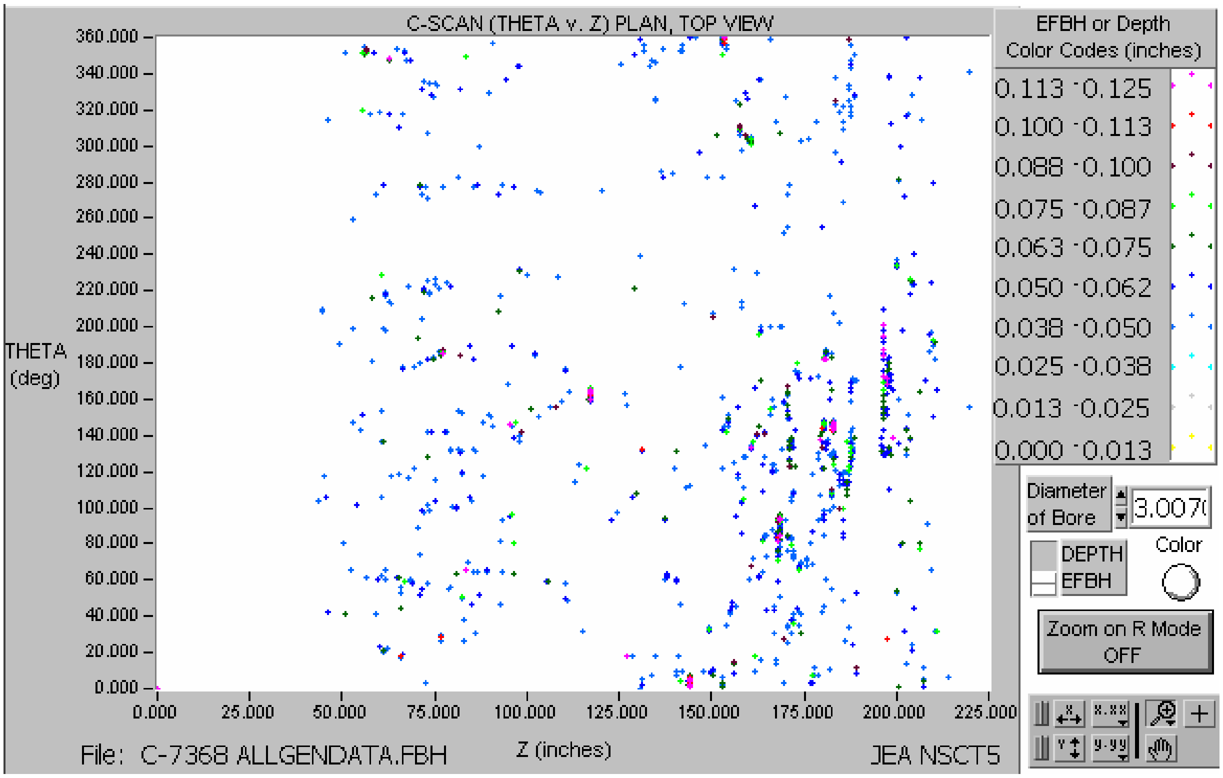

Figure 5. C-scan plot of all 9,682 ultrasonic data points collected during the boresonic examination of the JEA NSCT5 generator rotor.

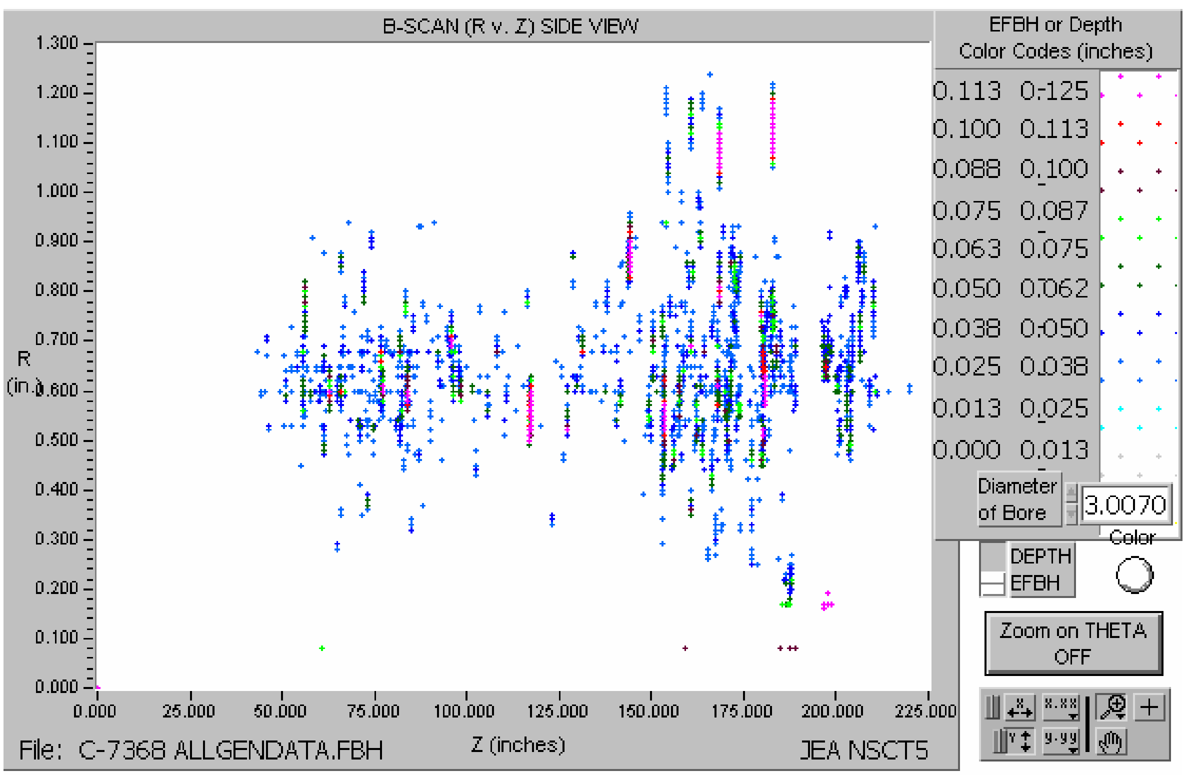

Figure 6. B-scan plot of all 9,682 ultrasonic data points collected during the boresonic examination of the JEA NSCT5 generator rotor.

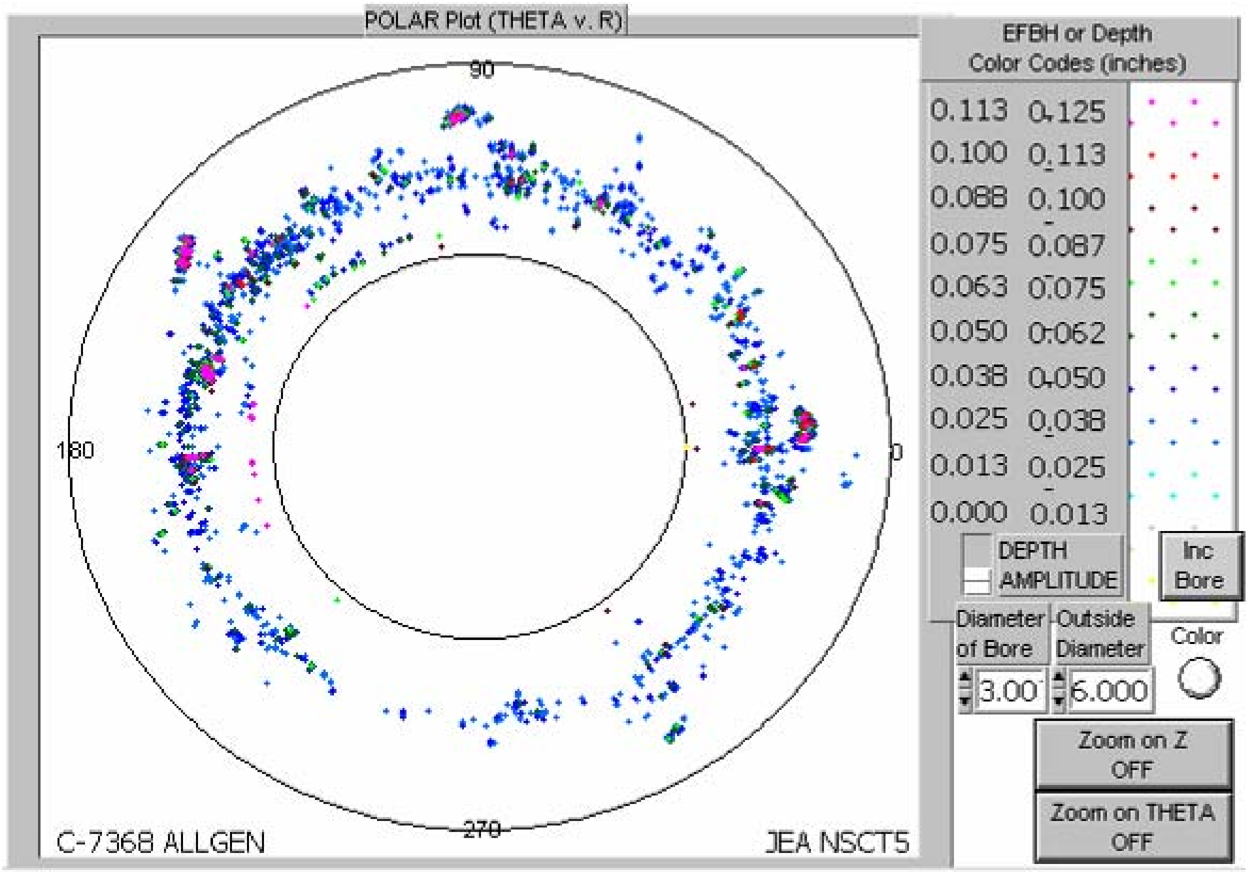

Figure 7. Polar plot of all 9,682 ultrasonic data points collected during the boresonic examination of the JEA NSCT5 generator rotor.

3.5 Engineering Analysis

3.5.1 Initial Flaw Size

The NDE examinations of the JEA NSCT5 generator rotor revealed 14 areas of WFMT intermittent indications on the bore surface ranging in size from 0.030 to 0.125 inches in axial length. The largest area of these intermittent indications was measured as 0.600 inches axial length. The UT data collected did not reveal any measurable depth of these WFMT indications. Therefore, an assumed flaw with a size of 0.150 in. radial depth and 0.600 in. axial length located on the bore surface in the high stress area under the main body of the generator rotor was used in the analysis as an initial flaw size. This assumed flaw size represents the largest flaw possibly existing on the bore surface, which could go undetected during the NDE examinations. This assumption is based on the results of the B-SURE® system performance evaluation as published in the EPRI report EPRI TR-107125.

3.5.2 Rotor Material Properties

A sample of the Northside Station U5 Generator rotor was provided by the Client for a chemical analysis in 2002 identifying the material of this rotor as ASTM A469 Class 4, which has the following published and calculated material properties as listed in Table III.

Table III. Material Properties for ASTM A-469 Class 4 Steel Alloys.

Material Property	Value (English Units)
Yield Strength	85.0 ksi
Charpy V-Notch Energy (CVN)	25.0 ft-lb. (@ room temperature)
Fracture Toughness (K_{IC})	83.7 ksi √in

3.5.3 Rotor Life Assessment

The maximum transient hoop mechanical and thermal stress in the JEA NSCT5 generator rotor was located under the middle of the rotor at 10% overspeed (3960 rpm) and was conservatively calculated as 54 ksi. The critical flaw size was calculated as 0.6873 in. radial depth and 2.7494 in. axial length. The total calculated number of start/stop cycles remaining for the Generator rotor is 8,320.

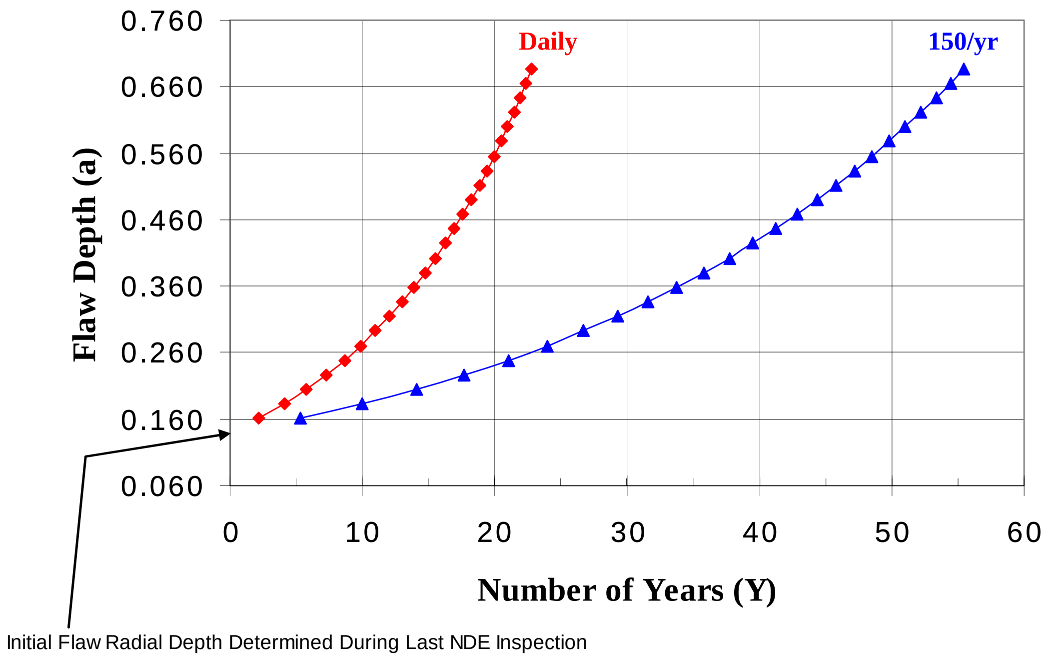

Figure 8. Life assessment plot of JEA NSCT5 showing number of years (depending on the start-stop cycles per year) versus flaw radial depth.

3.6 ET of Slot Dovetails & Wedging

The ET current examination of the rotor body coil slot dovetails and wedges on slots 1, 12, 13, and 24 revealed no recordable indications.

3.7 Fluorescent PT of Retaining Rings

The fluorescent PT examination of the ID and OD turbine and exciter end retaining rings revealed no recordable indications.

ATTACHMENT A: BORESONIC UT TABULATED DATA (C-7368)