OPPD
Omaha Public Power District
444 South 16th Street Mall
Omaha, Nebraska 68102-2247

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SUBJECT: Fort Calhoun Station (FCS) Steam Generator Eddy Current Test Report - 1998 Refueling Outage

Attached is the FCS Steam Generator Eddy Current Test Report which summarizes testing performed during the Spring 1998 Refueling Outage. This submittal fulfills the reporting requirements of FCS Technical Specification 3.17(5)(ii).

Please contact me if you have any questions.

Sincerely,

S. K. Gambhir
Division Manager
Nuclear Operations

JMC/tcm

Attachment

A001

C: E. W. Merschoff, NRC Regional Administrator, Region IV
L. R. Wharton, NRC Project Manager
W. C. Walker, NRC Senior Resident Inspector
Winston & Strawn (w/o Attachment)

FORT CALHOUN STATION
STEAM GENERATOR EDDY CURRENT TEST REPORT
1998 REFUELING OUTAGE

INTRODUCTION

This report summarizes steam generator eddy current results obtained during the Fort Calhoun Station (FCS) 1998 Refueling Outage. Omaha Public Power District (OPPD) submitted summaries of results of the two previous eddy current inspections to the NRC in the following documents:

- *Fort Calhoun Station Steam Generator Eddy Current Test Report - 1995 Refueling Outage,* dated July 18, 1995 (LIC-95-0138)

- *Fort Calhoun Station Steam Generator Eddy Current Test Report - 1996 Refueling Outage,* dated May 12, 1997 (LIC-97-082)

SCOPE OF EXAMINATION

ABB/Combustion Engineering conducted an inservice eddy current examination of the steam generator tubes at FCS in May 1998. The examination program was conducted to meet the requirements of FCS Technical Specification Section 3.17.

The test program included:

1. Full length bobbin coil testing of 100% of the tubes in steam generators RC-2A and RC-2B. This 100% testing encompassed 4913 tubes in RC-2A and 4929 tubes in RC-2B.

2. Rotating Pancake Coil (RPC) testing of the top of the hot leg tubesheet, including 26% of the tubes in steam generators RC-2A and RC-2B.

3. RPC testing in the tight radius U-bends of 48 tubes in each steam generator (20% of the tubes in rows 1 through 4).

4. RPC testing of a minimum of 20% of the dents, which measured greater than 5 Volts during the 1996 exam, at tube supports H1, H2, H8, and V1. This exam consisted of 569 test locations.

5. RPC program expansion to 100% of the dents greater than 5 volts at H8, 20% of the remaining tubes at H8, and 20% of the dents greater than 5 volts at the drilled tube support plate at H7. This expansion encompassed 1053 exams, and was performed as a result of two circumferential cracks being found at dented drilled support intersections in each steam generator at H8.

6. RPC exams of 216 locations at the top of the cold leg tubesheet in steam generator RC-2B to assess whether circumferential volumetric indications (CVIs), first identified in 1996, represented an active damage mechanism.

7. RPC exams to characterize approximately 255 indications detected with the bobbin probe.

8. RPC exams of 20% of mechanical rolled tube plugs (47 exams).

BOBBIN COIL EXAMINATIONS AND RESULTS

The tubes in the bobbin coil inspection plan were examined full length. The data were independently analyzed by two groups of certified Level IIA or Level III data analysts. Discrepancies between the two sets of evaluation results were reviewed and resolved by a Lead Level III Eddy Current Examiner.

The examination was conducted with a Zetec MIZ-30® digital eddy current acquisition system and analyzed utilizing the Eddynet 95® digital analysis system. The frequencies utilized during the bobbin coil examination were as follows:

400 kHz differential and absolute
100 kHz differential and absolute
600 kHz differential and absolute
20 kHz differential and absolute
400/100 kHz differential support ring mix
600/100 kHz differential copper mix
400/600/100 kHz differential transition mix
400/100 kHz absolute support ring mix

The primary frequency of 400 kHz satisfied the requirements of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code for the examination of non-ferromagnetic steam generator tubing. Dent analysis was performed using the differential support mix and a voltage base of 2.75 volts on the 20% OD ASME signal, which is consistent with current industry practices.

The 100 kHz frequency was provided to assist in the confirmation of flaw indications. The 100 kHz absolute frequency detected gradual wall thickness variations. The 600 kHz frequency was provided to assist the analysts with additional mixing capabilities in the event of excessive outside diameter (OD) tube deposits and diametric transitions. The 20 kHz frequency was provided to facilitate locating the probe position in the steam generator. The 400/100 kHz and the 600/100 kHz differential mixes were used to eliminate the tube support and OD tube deposit signals. The 400/600/100 kHz mix was used to evaluate areas of geometry changes such as top of tubesheet expansion transitions. The 400/100 kHz absolute mix was used to detect gradual wall loss.

All tubes were inspected full length with the 0.540" or 0.560" bobbin probe, and indications were flagged for later characterization with qualified techniques. Tubes considered defective were identified using a "plug on detection" methodology in the following manner:

> Bobbin coil indications which were confirmed by RPC to be volumetric and showed change from a review of 1984 and 1985 historical data were plugged regardless of size. All crack-like indications were plugged, regardless of whether they showed change from history. Circumferential indications were stabilized as well. Any tube which obstructed passage of the 0.540" bobbin probe was also plugged. Indications flagged by the bobbin coil, but which did not confirm with RPC were dispositioned as requiring no further action and were left in service.

All pluggable indications are reported in Tables 1 and 2. Support notation for each steam generator is shown in Figure 1. Depth estimates were only made on pluggable indications for the purpose of providing input to assessments of overall steam generator condition. No tubes were left in service on the basis of sizing of indications. The list of indications with depth sizes is considerably smaller in this report than in the report submitted to the Nuclear Regulatory Commission after the 1996 Refueling Outage. Signals such as those reported in 1996 are not included in this report because (1) those types of signals were dispositioned as non-reportable through the use of RPC and historical reviews, (2) those bobbin signals are considered not to represent actual tube wall degradation, and (3) use of sizing techniques on those types of signals does not provide useful data. Therefore, sizing of those types of signals was not performed in 1998.

Bobbin coil dent measurements were performed using the 400/100 kHz differential mix channel. Dent sizing is based on the 20% Flat Bottom Holes in the ASME standard set at 2.75 volts. This method is consistent with current industry dent sizing practice, and was adopted at FCS during the 1996 Refueling Outage. A comparison of 1998 to 1996 dent data indicates that there may be a slow progression of denting occurring in the FCS Steam Generators. This progression is slight, and is only noticeable now that the industry-standard dent measurement technique has been adopted. The dent measurement technique which was used prior to the 1996 Refueling Outage (dents were measured using the 400 KHz absolute, with one volt set to equal 1 mil radial reduction) resulted in much smaller voltages than what is seen with the current technique. As a result, small changes in dent size are more evident with the current sizing technique as a result of increased sensitivity. However, it is concluded that significant dent progression is not occurring based on the fact that no tubes required plugging due to failure to allow passage of the 0.540" bobbin probe.

ROTATING PANCAKE COIL EXAMINATIONS AND RESULTS

Rotating pancake coil examinations were performed at the top-of-tubesheet transitions on the hot legs, in low-row U-bends, at dented tube support intersections, and at bobbin coil suspect indications as a diagnostic tool.

The tubes in the Top of the Tubesheet RPC Program were inspected in the expansion transition regions of each steam generator. The data were analyzed for the presence of crack-like indications similar to those found in the expansion transition regions at other plants. Terrain plots were used during the analysis effort to improve the probability of detecting circumferential cracks.

The RPC exams performed at U-bends, dents, freespan sections, and tube support intersections were performed to determine if stress corrosion cracking is present in suspect areas of the steam generators, to verify bobbin coil results, and to characterize the indications seen with the bobbin coil probe.

Plus Point® and Pancake Coil RPC probes were both used during this inspection. Various versions of the Plus Point® probe were used for the bulk of the RPC examination and the Single Coil Pancake probe was used on a limited basis to inspect a sample of rolled mechanical tube plugs.

The frequencies used for the 3 coil top-of-tubesheet examination were as follows:

400 kHz Pancake, Mid-Freq. Plus coil, and High-Freq. Pancake coil
300 kHz Pancake and Mid-Freq. Plus coil
100 kHz Pancake and Mid-Freq. Plus coil
700 kHz Pancake and High-Freq. Pancake coil
20 kHz Pancake and Mid-Freq. Plus coil

The frequencies used for the single coil U-bend RPC examinations were as follows:

400 kHz Mid-Freq. Plus coil
300 kHz Mid-Freq. Plus coil
200 kHz Mid-Freq. Plus coil
100 kHz Mid-Freq. Plus coil
20 kHz Mid-Freq. Plus coil

The frequencies for the Flex probe RPC examinations were as follows:

400 kHz Pancake and Mid-Freq. Plus coil
300 kHz Pancake and Mid-Freq. Plus coil
100 kHz Pancake and Mid-Freq. Plus coil
20 kHz Pancake and Mid-Freq. Plus coil

The frequencies for the Single Coil RPC tube plug examinations were as follows:

400 kHz Mid-Freq. Pancake coil
300 kHz Mid-Freq. Pancake coil
200 kHz Mid-Freq. Pancake coil
100 kHz Mid-Freq. Pancake coil

There was no circumferential cracking found during any of the examinations at the top of tubesheet expansion transitions. Diagnostic exams were performed on approximately 255 bobbin coil indications, and tubes with volumetric indications in these areas which showed change from historical data were preventively plugged. The number of tubes plugged due to volumetric indications reduced significantly from 1996 to 1998, and little growth was seen when comparing indications to historical data.

A total of four circumferential crack-like indications were found in dented tube support intersections at H8, two in each steam generator. All four of these indications were less than 85 degrees in circumferential extent, and all were at locations with dents greater than 5 volts. All four of these circumferential indications were stabilized and plugged.

There were 13 axial indications recorded at various elevations of both steam generators. All were investigated by historical review and rotating coil technology, and the tubes were plugged.

Circumferential Volumetric Indications (CVIs), first seen during the 1996 Refueling Outage exam, were originally flagged with the bobbin coil examination as Distorted Tubesheet Indications (DTIs). CVIs were detected at the top of the cold leg tubesheet in both steam generators. However, historical reviews of the CVIs found in 1998 indicate that the damage mechanism is not currently active, and the CVIs found in 1998 are bounded in severity by those identified in 1996. All CVI indications were stabilized and plugged.

TUBE PULL RESULTS

Sections of two tubes were pulled from steam generator RC-2B for destructive examination during the 1998 Refueling Outage. These two tubes exhibited indications which appeared linear and potentially crack-like on the terrain plots generated from Plus Point® data, but did not exhibit the phase correlation expected of actual through-wall tube degration. These indications had been dispositioned by the analysts as Less Than Zero (LTZ) indications during the 1996 Refueling Outage examination, representing that the eddy current response fell outside the defect plane, and the indications were caused by a non-degradation related condition. A search of industry tube pull and laboratory data was performed prior to the 1998 Refueling Outage to definitively support this conclusion. None of the industry data reviewed showed eddy current responses similar to the LTZ indications. It was therefore concluded that two LTZ indications should be pulled during the 1998 Refueling Outage to verify their origin.

Both indications pulled were selected based on largest amplitude Plus Point® signals with phase angles closest to the defect plane. One of the selections was detectable by the bobbin coil, and the other was not.

Eddy current testing performed on the tube sections immediately after the tube pull indicated that the LTZ indications disappeared during the tube pull process. The pulled tubes were metallographically characterized and subjected to burst test at the ABB Combustion Engineering facilities in Windsor, CT. It was determined that the indications were caused by a non-degradation related condition, and were most likely caused by deposits.

IN-SITU PRESSURE TEST RESULTS

Eight tubes with defects were tested with the ABB/CE In-Situ Pressure Test device. These tubes were tested to demonstrate that leakage would be below allowable limits at normal operating differential pressure (NODP) and at 1.4 times peak accident (main steam line break (MSLB)) pressure, and that they would be able to sustain a pressure of 3 times NODP without burst in accordance with NRC Regulatory Guide 1.121.

The eight indications tested covered axial indications, non-oriented volumetric indications, and circumferentially oriented volumetric indications. No single circumferential indications (SCIs) were in-situ pressure tested, primarily based on their short circumferential extent. Table 3 shows the tubes tested with the In-Situ Pressure Test method and gives the results of each test. None of the eight tubes leaked at pressures up to 3 times NODP.

The indications tested by this method bounded the severity of the other known indications in the steam generators, as well as any indications assumed to be present but not detected. Therefore, based on the In-Situ pressure test results and extensive historical reviews of eddy current data which show little or no growth of indications in the FCS steam generators since 1984, operation until the next scheduled inspection is justified.

CONCLUSIONS

As a result of the inspection, OPPD has reached the following conclusions:

1. Bobbin coil indications of through-wall degradation generally showed little change from the last inspections and only minor change from the 1984 100% inspection.

2. After a 26% top-of-tubesheet expansion transition inspection on the hot leg side of each steam generator, there were no circumferential cracks detected at the top-of-tubesheet. Four short circumferential crack-like indications were detected as a result of RPC examinations performed at dented tube support plate intersections. No cracking was identified in the tight radius U-bends.

3. The most notable indications for all inspections included:

   Circumferential Volumetric Indications at the top-of-tubesheet in the cold leg side of both steam generators. This degradation mechanism does not appear to be active based on historical reviews performed.

   Volumetric indications in both steam generators which required plugging due to minor change when compared to data from 1984 and 1985.

   Axial indications detected in both steam generators, both in the freespan and just above the top of the hot leg tubesheet. These appear to be dormant or very slowly progressing based on historical reviews performed.

Single circumferential indications at dented tube support intersections at hot leg H8 tube support plate in each steam generator.

5. All tubes with the above notable indications were plugged. Circumferential indications were stabilized as well. Overall, 12 tubes were plugged in steam generator RC-2A and 24 tubes were plugged in steam generator RC-2B. In addition, two plugs which were removed from previously plugged tubes to facilitate removal of steam generator flow orifice plates were replaced in the hot leg side of steam generator RC-2A.

6. It was confirmed through tube pull results that LTZ indications seen with the Plus Point® probe do not represent tube wall degradation and are likely caused by deposits.

7 Eight tubes in steam generator RC-2B were examined with an in-situ pressure test tool to verify structural integrity. All tubes tested met the requirements of NRC Regulatory Guide 1.121, August 1976, and none showed evidence of leakage.

8. Based on the results of the extensive eddy current examination and the in-situ pressure tests performed, operation of the FCS steam generators until the next scheduled inspection during the 1999 FCS Refueling Outage is justified.

TABLE 1
LIST OF RC-2A TUBES PLUGGED

Definitions:

CVI - Circumferential Volumetric Indication
PIT – Pit-like Indication
SAI - Single Axial Indication
SCI - Single Circumferential Indication
SVI - Single Volumetric Indication

Row/Line	Flaw Type	Estimated Depth (%)	Location	Comments
4/1	SVI	37	CTS+2.19	
16/71	SVI	15	CTS+0.00	
17/88	N/A	N/A	N/A	Previously plugged tube. HL plug reinstalled after removal of flow orifice plates
17/100	N/A	N/A	N/A	Previously plugged tube. HL plug reinstalled after removal of flow orifice plates
20/77	PIT	54	HTS+0.77	
24/47	CVI	66	CTS-0.02	
24/51	CVI	41	CTS-0.17	
24/63	SVI	46	CTS+0.10	
38/63	SVI	10	HTS+0.09	
40/73	SVI	63	CTS+0.21	
85/96	SCI	25	H8-0.54	
91/62	SAI	30	H1-0.07	
94/49	SAI	2	H1-0.05	
97/54	SCI	62	H8+0.50	

TABLE 2
LIST OF RC-2B TUBES PLUGGED

Definitions:

CVI - Circumferential Volumetric Indication
LTZ - Less than Zero Signal
MAI - Multiple Axial Indications
PIT – Pit-like Indication
SAI - Single Axial Indication
SCI - Single Circumferential Indication
SVI - Single Volumetric Indication

Row/Line	Flaw Type	Estimated Depth (%)	Location	Comments
17/62	CVI	60	CTS+0.01	
22/89	N/A	N/A	N/A	Pulled tube, contained LTZ signal, verified not to represent tube wall degradation
24/55	SAI	34	HTS+0.93	
29/80	PIT	2	HTS+16.28	
31/64	CVI	77	CTS+0.07	
32/63	CVI	55	CTS+0.06	
32/65	CVI	28	CTS+0.09	
33/82	SVI	18	HTS+0.32	
35/6	SVI	65	H4+1.98	
35/74	N/A	N/A	N/A	Pulled tube, contained LTZ signal, verified not to represent tube wall degradation
40/65	CVI	52	CTS+0.16	
40/75	SVI	55	HTS+0.00	
48/69	PIT	4	HTS+3.23	
76/85	SAI	35	H3-0.39	
80/83	SAI	51	H6+21.25	
87/66	SAI	5	H7-2.39	
88/55	SAI SAI	9 52	H6-0.66 H6-1.36	
89/74	MAI	29	H1+0.05	
90/73	SAI	39	H1+0.14	
90/87	SAI	79	H8-0.17	
91/72	SAI	63	H8-0.86	
93/72	SAI	39	H8-0.69	
94/59	SCI	18	H8+0.30	
95/62	SCI	4	H8+0.29	

TABLE 3
IN-SITU PRESSURE TESTS

Definitions:

CVI - Circumferential Volumetric Indication
DSI - Distorted Support Indication
DTI - Distorted Tubesheet Indication
NDD - No Detectable Degradation
NQI - Non Quantifiable Indication
SAI - Single Axial Indication
SVI - Single Volumetric Indication

S/G	Tube	Indication Type	Location	RPC Voltage	Length	Width	Bobbin Voltage	Bobbin Call	Maximum Pressure (psig)	Leakage?
RC-2B	R17L62	CVI	CTS+0.01	0.28	0.29"	360 Deg	4.84	DTI	4900	NO
RC-2B	R31L64	CVI	CTS+0.07	0.16	0.23"	150 Deg	5.51	DTI	4900	NO
RC-2B	R32L63	CVI	CTS+0.06	0.28	0.26"	182 Deg	2.07	DTI	4900	NO
RC-2B	R35L6	SVI	H4+1.98	3.19	0.28"	0.33"	3.93	NQI	4550	NO
RC-2B	R40L75	SVI	HTS+0.0	0.26	0.3"	0.3"	N/A	NDD	4575	NO
RC-2B	R90L73	SAI	H1+0.14	2.02	0.57"	0.39"	1.23	DSI	4550	NO
RC-2B	R90L87	SAI	H8-0.17	0.11	0.47"	0.16"	N/A	NDD	4600	NO
RC-2B	R91L72	SAI	H8-0.86	0.19	0.33"	0.28"	N/A	NDD	4575	NO

FIGURE 1
FCS STEAM GENERATOR ELEVATION DRAWING

HTE	Hot leg Tube End
HTS	Hot Leg Tubesheet
H1-H6	Hot Leg Full Supports
H7	Hot Leg Partial Egg Crate
H8	Hot Leg Partial Drilled Support
DBH	Diagonal Bar Hot Leg
V1-V3	Vertical Supports
DBC	Diagonal Bar Cold Leg
C8	Cold Leg Partial Drilled Support
C7	Cold Leg Partial Egg Crate
C6-C1	Cold Leg Full Supports
CTS	Cold Leg Tubesheet
CTE	Cold leg Tube End