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"Susquehanna Replacement Steam Dryer Updated Stress Analysis at Extended Power Uprate Conditions"

HITACHI

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Engineering Report

Susquehanna Replacement Steam Dryer
Updated Stress Analysis at Extended Power Uprate Conditions

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REVISION SUMMARY

Rev	Changes Incorporated in Current Revision
0	Initial Document

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ACRONYMS AND ABBREVIATIONS

Item	Short Form	Description
1	ASME	American Society of Mechanical Engineers
2	BWR	Boiling Water Reactor
3	CLTP	Currently Licensed Thermal Power
4	EPU	Extended Power Uprate
5	EPU SF	Extended Power Uprate Scale Factor
6	FEA	Finite Element Analysis
7	FIV	Flow-Induced Vibration
8	GE	General Electric Company
9	GEH	GE Hitachi Nuclear Energy
10	MSL	Main Steam Line
11	NRC	Nuclear Regulatory Commission
12	OLTP	Original Licensed Thermal Power
13	Pb	Primary Bending Stress Intensity
14	Pm	Primary Membrane Stress
15	PPL	Pennsylvania Power & Light
16	PSD	Power Spectral Density
17	PT	Pressure Transducers
18	RMS	Root Mean Squared
19	RPV	Reactor Pressure Vessel
20	SG	Strain Gage
21	SRSS	Square Root of the Sum of Squares
22	SSES	Susquehanna Steam Electric Station
23	SUPF	Stress Under-Prediction Factor
24	TC	Test Condition
25	ts	Time Segment
26	VPF	Vane Passing Frequency

1. Executive Summary

This report provides an update to the Susquehanna Steam Electric Station (SSES) Replacement Steam Dryer stress analysis report, Reference 1, as a result of analysis of startup test data gathered during a power ascension test program of the instrumented replacement steam dryer installed at SSES Unit 1. This update to the Reference 1 stress report consists of the following elements:

1. Calculate a revised Stress Under-prediction Factor (SUPF) [[ ]] from the instrumented Unit 1 replacement steam dryer
2. Calculate a revised stress scaling factor for [[ ]] This scaling factor is defined as the EPU Scaling Factor (EPU SF).
3. Perform an assessment of the effect on dryer fatigue due to the presence of vibration induced by the vane passing frequency (VPF) excitation of the reactor recirculation pumps.

The results of the three evaluation elements are as follows:

1. The revised SUPF is [[ ]], which is a reduction from the previously SUPF of [[ ]]
2. The revised EPU SF is [[ ]], which is a reduction from the previous EPU SF of [[ ]]
3. Significant recirculation pump VPF content (measured spike of pressure spectrum at VPF frequency) existing in a test condition may cause a slight increase in the overall vibration stresses on the dryer. [[ ]]

This report contains the incorporation of the above elements into the FIV and ASME stress tables from Reference 1. The update of the stress tables consisted of multiplication of the FIV stresses by the [[

]] Stress margins to acceptance criteria were then re-calculated. The revised stress evaluation demonstrates the acceptability of the SSES replacement dryer design at the projected EPU operation condition (120% OLTP).

An alternate assessment of fatigue margin is contained in Appendix A to this report. The results of the Appendix A evaluation additionally show that the replacement steam dryer has adequate fatigue margin at full EPU conditions.

2. INTRODUCTION and BACKGROUND

The purpose of this report is to provide an update to the Reference 1 SSES replacement steam dryer stress analysis by incorporating the information from instrumented steam dryer startup test data gathered during the SSES Unit 1 power ascension in 2008. Data from the power ascension testing is used to benchmark the SUPF and EPU SF used in the Reference 1 analysis. Data from the test condition at which the [[ ]] also allows the performance of a quantitative evaluation of the stress contribution of the VPF vibration.

The flow induced vibration analysis in Reference 1 applied fluctuating pressure loading to a FE model of the replacement steam dryer to calculate the steam dryer transient dynamic responses. The pressure loads used in the Reference 1 analysis were developed by Continuum Dynamics, Inc. (CDI) based on in-plant steam line pressure measurements taken at steam flow conditions approximating 94% of the full EPU steam flow. In order to evaluate uncertainties in the steam dryer structural frequency response, the time scale of the loads was stretched by increments of 2.5% to plus and minus 10% from the nominal value to create frequency shifts in the load definition. In all the transient response analyses, Rayleigh damping equivalent to a 1% damping ratio was applied. The maximum stresses for each of the modeled dryer components were searched from all the solutions over the range of time histories analyzed. Based on a benchmarking comparison of the analytical results to strain gauge data taken from on-dryer instrumentation in 1985, a scaling factor, the SUPF, was developed and applied to address underprediction in the stresses due to both flow and mechanically induced vibration. A second scale factor, the EPU SF, was developed based on power ascension measurements and used to extrapolate the stress results of 94% EPU to the full EPU conditions. The resulting stress values were used for component fatigue evaluation. The Reference 1 stress report results showed that the replacement steam dryer met all stress acceptance criteria.

The SSES Unit 1 replacement steam dryer was instrumented with [[ ]] The locations of these instruments are shown in Appendix A of Reference 2. A power ascension test program for the Unit 1 replacement steam dryer was implemented during 2008, during which test data with all four main steam isolation valves (MSIV) open was gathered from approximately [[ ]]. Additional power ascension testing included

1. MSIV closure testing to simulate steam flow velocities in the remaining open main steam lines approximating [[ ]] (simulate the same design load configuration used in the Reference 1 stress analysis) and to simulate full EPU conditions.

2. Core flow sweeps to the [[ ]] on the steam dryer.

The results of the steam dryer power ascension test program to [[ ]] are contained in Reference 2. Data evaluation of the startup test data showed that all acceptance limits were met for [[ ]] with sufficient margin to acceptance limits to accommodate operation at the full EPU power condition.

The update of the Reference 1 stress evaluation consists of the following elements:

1. Calculate a revised SUPF [[ ]]

2. Calculate a revised EPU SF [[ ]]

3. Apply the [[ ]]

4. Apply the revised SUPF to the FE analysis maximum FIV stress results [[ ]] which were adjusted to account for weld factors and plate mismatch factors.

5. Add the [[ ]] adjusted for the revised SUPF.

6. Apply the revised EPU SF to the revised FE analysis maximum FIV results from element 5 above.

3. TEST CONDITIONS

Appendix B of Reference 2 contains the plant parameters for all SSES Unit 1 replacement steam dryer test conditions. The test conditions used for the evaluations contained in this report are as follows:

Test Condition 1J: [[

]]

Test Condition 2A2: [[

]]

Test Condition 2B2: [[

]]

Test Condition 3D: [[

]]

As reported in Reference 2, the highest strain response on the replacement steam dryer instrumentation [[

]]

4. SUPF, EPU SF, UNCERTAINTY and BIAS of ANALYSIS *versus* TEST

4.1 Determination of SUPF from 2008 Test Data

The availability of test data from several test conditions and from multiple sensors provides the opportunity to re-evaluate the SUPF used in the Reference 1 stress report. Figures 25 and 26 of Reference 2 provided a comparison of the SSES 1985 test data versus test data at an equivalent power level from the replacement steam dryer power ascension test program in 2008. These data indicate [[

]]

SUPF is defined as the [[

]]

In order to determine the SUPF, [[

]] The startup test data taken at each test condition consist of three data sets of approximately 5 minutes duration. For this evaluation, [[

]] with the [[ ]] analysis duration in the dryer FE time-history analysis contained in Reference 1.

In each data time segment, Root-Mean-Squared (RMS) and maximum strains are evaluated. The computed RMS and maximum strains for all time segments are then averaged. The averaged values are named [[

]]

For the evaluation of the SUPF, strain gage time data from test condition 3D were chosen for comparison with the calculated instrument location strain data from the Reference 1 FE analysis. [[

]] as the FE analysis case [[

]] It is therefore considered a reasonable and conservative test case for the comparison.

Table 1 shows the [[ ]] and the finite element analysis results. [[

]]

Table 1: [[

]]

Comparisons of spectral strain from TC 3D and analysis are shown for all strain gages in Figures 1 to 9. [[

]] In Figures 1 to 9, the term "U-Model" refers to the GEH designation of the analysis FE model used for the Reference 1 analysis.

Figures 1 to 9 show that analysis under-predicts low frequency response at all strain gage locations. The prediction is better for some strain gages in mid frequency range. However, the spikes around [[ ]] predicted in analysis are generally not observed in the test measurements. [[

]] Pressure transducer measurements indicate no significant pressure spikes at [[ ]] The test measurements do show a small spike at the VPF frequency of approximately 129-Hz on most of the strain gages. As expected,

[[

]] Figures 1 through 9 provide a

[[

]]

Individual [[

]]

The actual calculation of the SUPF [[

]] The updated SUPF is equal to[[ ]]

The updated dryer analysis SUPF [[

]]

[[

]]

Figure 1

[[

]]

Figure 2

[[

]]

Figure 3

[[

]]

Figure 4

[[

]]

Figure 5

[[

]]

Figure 6

[[

]]

Figure 7

[[

]]

Figure 8

[[

]]

Figure 9

[[

]]

Figure 10

4.2 EPU Scaling Factor

The EPU SF used in Reference 1 was developed using previous MSL measurements, the 1985 dryer measurements and the scale model measurements. [[

]]

Two methods were employed to determine the [[

]]

Out of the four test conditions (see Section 3), [[

]]

The strain gage [[ ]] are shown in Table 2.

Table 2 [[ ]] for Test Conditions

[[

]]

It should be noted [[

]]

Calculation of the EPU SF is based on a ratio [[ ]] The individual ratios are tabulated in Table 2 for [[ ]] The revised EPU SF for the analysis is then determined by averaging from the individual EPU SF ratios for the [[

]]

The second method for the determination of the EPU SF used [[ ]]

Steady-state power ascension data sets for [[

]]

The EPU SF using this method is determined by [[

]] The revised EPU SF is [[ ]]

Since the EPU SF [[

]] will be used for updating the SSES replacement steam dryer stress summary tables.

4.3 Uncertainty

Because the SUPF is calculated by comparing the strains predicted by the analysis to the actual strains measured on the dryer, the SUPF in Section 4.1 determines the [[ ]] EPU. There are also uncertainties associated with the test and the analysis. The following is a discussion of various uncertainties.

[[

]]

]]

Table 3: [[

]]

Figure 11 shows [[

]] As shown in Figure 13, the difference in the [[

]]

Figure 11

[[

]]

Figure 12

[[

]]

Figure 13

In summary, three types of uncertainties are quantitatively assessed. They are listed in Table 5. The total uncertainty is calculated as the SRSS of all quantified uncertainties. The total uncertainty calculated is [[ ]]

Table 5: Overall Uncertainty Calculation

Uncertainty Parameter	Value
[[	

]]

5. VANE PASSING FREQUENCY STRESS ANALYSIS

Reference 2 documents that the highest VPF content exists at the [[

]]

Since running the dryer FEA using the [[

]]

[[

]]

6. Update of FIV and ASME Stress Tables

Table 7 is the FIV stress table, Table 6.7-1 (SSES Dryer Component Fatigue Margin under EPU Condition), from the January 2008 report (Reference 1) updated based on the evaluations of the on-dryer measurements performed in this report. The update includes: 1) the change of the SUPF and EPU SF, and 2) [[ ]] The updated results in Table 7 show that all dryer components have positive fatigue margin at full EPU conditions. The minimum fatigue margin is [[ ]]

The SUPF applied in Table 7 is the [[ ]] The analysis uncertainty is discussed in Sec. 4.3. The quantified total uncertainty for the dryer is [[ ]] If this uncertainty is applied to the component with minimum margin, the minimum component fatigue margin is reduced from [[ ]]

In Table 7, the [[ ]]

Table 7:
Updated SSES Dryer Component Fatigue Margin under Projected EPU Condition

[[

]]

To include the adjustment and update of FIV stresses in the ASME stress table, Table 7.1-1 (EPU ASME Results for Normal, Upset, Emergency and Faulted Conditions: Maximum Stresses) from Reference 1 has been also updated as shown in Table 8. It indicates that the stresses for all structural components are under the allowable ASME Code limits at EPU operating conditions.

Table 8

Updated Table 7.1-1 EPU ASME Results for Normal, Upset, Emergency and Faulted Conditions:

[[

]]

7. Alternate Assessment of Dryer Fatigue Margin

Appendix A contains an additional fatigue margin assessment of the replacement steam dryer. The results of this assessment indicate that the stress analysis results presented in Section 6 of this report are conservative.

8. CONCLUSIONS

An update was performed to the Susquehanna Steam Electric Station (SSES) Replacement Steam Dryer stress analysis report, Reference 1, as a result of analysis of startup test data gathered during a power ascension test program of the instrumented replacement steam dryer installed at SSES Unit 1. A modified SUPF and EPU SF were calculated based on the instrumented dryer test data compared to the Reference 1 analysis. The effect of VPF FIV loading on the dryer FIV stress was performed.

The fatigue evaluation indicates that at full EPU conditions, all dryer components meet the fatigue acceptance criteria with adequate or high margins, and the replacement Susquehanna design is structurally adequate to accommodate the vibration environment at EPU condition. The results of this evaluation indicate that the fatigue margins shown in Reference 1 were conservative.

The updated ASME load combination analysis results indicate that the stresses for all structural components remain under the allowable ASME Code limits at EPU operating conditions. Therefore, the fatigue evaluation and ASME load combination analysis demonstrates the acceptability of the Susquehanna replacement steam dryer design.

9. REFERENCES

[1] "Susquehanna Replacement Steam Dryer Stress Analysis at Extended Power Uprate Conditions", GE-NE-0000-0079-2250-P-R0, January 2008.

[2] GE-NE-0000-0085-2413-P-R0, "Susquehanna Unit 1 Replacement Steam Dryer Vibration Instrumentation Program NRC Summary Report", July 2008.

Appendix A: Alternate Assessment of Replacement Steam Dryer Fatigue Margin

This appendix provides:

- A Summary of the dryer strain range as compared with the acceptance limits established in Reference 1 and a projection of expected maximum stress amplitude,

  Allowable load factors to maintain expected fatigue [[

  ]]

Three test conditions shown in Table A-1 were evaluated in this assessment. The conditions were selected to be close to the current maximum Unit 1 core thermal power of 3733 MWth. [[

]]

Table A-1: Summary of Test Conditions and Plant Process Data used in this Assessment

[[

]]

Projected EPU Stress from Measured Strain Range Data

In the dryer acceptance limit report GE-NE-0000-0080-2994-R4, [[

]]

There were two methods used to assess the instrument acceptance criteria for the strain gauges in Reference 1:

[[

]]

The most limiting strain and acceleration values from both methods were used for the acceptance limits. These limits are summarized in Table A-2. Trending projections and the full EPU steam flow testing summarized in Reference 2 demonstrate that all sensors were expected to meet both Level 1 and Level 2 acceptance values at EPU.

Table A-2: Summary of Strain Range Limits for Reference 1, Table 3-4.

[[

]]

The acceptance limits were designed to be conservative. [[

]] Table A-3 summarizes the test results for these three conditions.

Table A-3: Summary of Measured Strain Ranges as a Percent of the Level 1 Acceptance Limits

[[

]]

To project the peak stress amplitude at the maximum location on the dryer, [[

]] The results are presented in Table A-4.

Table A-4: Projections of Dryer Peak Stress based on Strain Test Data

[[

]]

Projected Stress Amplitude based on Strain Range Data

Based on the assessment summarized in Reference 1 [[

]]

[[

]]

Figure A-1: [[ ]]

[[

]]

Figure A-2: [[

]]

[[

]]

The ASME Section III, Design Fatigue for Austenitic Steels, Curve C (Reference 4) is used to [[

]]

The result of this assessment is presented in Table A-5. [[
]]

Fatigue Summary

- [[

-

]]

Table A-5: [[ ]]

[[

]]

References:

[1] GE-NE-0000-0080-2994-P-R4, "Susquehanna Replacement Steam Dryer Instrumentation Acceptance Criteria – Dryer Mounted Instrumentation", April 2008.

[2] GE-NE-0000-0085-2413-P-R0, "Susquehanna Unit 1 Replacement Steam Dryer Vibration Instrumentation Program NRC Summary Report", July 2008.

[3] GE-NE-0000-0079-2250-P-R0, "Susquehanna Replacement Steam Dryer Stress Analysis at Extended Power Uprate Conditions", January 2008.

[4] ASME B&PV Code, Section III, 1989 Edition with no Addenda.