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Engineering Report

Main Steam Line Limit Curve Adjustment During Power Ascension

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REVISION SUMMARY

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ACRONYMS AND ABBREVIATIONS

Item	Short Form	Description
1	ACM	Acoustic Circuit Model
2	Ave	Average
3	EPU	Extended Power Uprate Power, 3952 MWt
4	FE	Finite Element
5	FIV	Flow-induced vibration
6	GEH	GE Hitachi Nuclear Energy
7	Hz	Hertz
8	ID	Identification
9	LC1	Level 1 Acceptance Limit
10	LC2	Level 2 Acceptance Limit
11	LCF	Limit Curve Factor
12	MSIV	Main Steamline Isolation Valve
13	MSL	Main Steam Line
14	MWt	Megawatt Thermal
15	NRC	Nuclear Regulatory Commission
16	OLTP	Original Licensed Thermal Power, 3293 MWt
17	PBLE	Plant Base Load Evaluation
18	PPL	PPL Susquehanna, LLC
19	PS	Power Spectra
20	PSD	Power Spectral Density
21	Psi	Pounds per square inch
22	RMS	Root-Mean-Squared
23	RPV	Reactor Pressure Vessel
24	SG	Strain Gage
25	SRSS	Square Root Sum of Squares
26	SSES	Susquehanna Steam Electric Station
27	Stdev	Standard Deviation
28	TC	Test Condition
29	VPF	Vane Passing Frequency

1. EXECUTIVE SUMMARY

PPL will be using Main Steam Line (MSL) limit curves to monitor the Susquehanna Steam Electric Station (SSES) replacement steam dryers for acceptable structural integrity to potential adverse flow effects. GEH developed in Reference [1] updated MSL limit curves. The Reference [1] MSL limit curves will be used for monitoring the replacement steam dryer structural integrity during SSES Unit 1 power ascension above 3733 MWt and SSES Unit 2 power ascension above 3489 MWt.

The Level 1 acceptance criterion for the replacement steam dryer is that the dryer alternating stress amplitude does not exceed 13,600 psi. PPL has also imposed a Level 2 alternating stress acceptance criterion of 11,000 psi. The MSL limit curves are developed to provide a means for monitoring the plant MSL strain gage instrumentation to ensure that the steam dryer Level 1 and Level 2 alternating stress criteria are not exceeded during the plant power ascension.

The Level 1 Limit Curve (LC1) is used to monitor against the Level 1 acceptance criterion. LC1, if exceeded across the entire MSL power spectrum, would indicate that some dryer component is at or above the Level 1 alternating stress acceptance criterion of 13,600 psi. The Level 2 Limit Curve (LC2) is used to monitor against the Level 2 acceptance criterion. LC2, if exceeded across the entire MSL power spectrum, would indicate that some dryer component is at or above the Level 2 alternating stress acceptance criterion of 11,000 psi. Maintaining the measured MSL response below the Level 1 Limit Curve assures that the Level 1 acceptance criteria does not exceed 13,600 psi. During plant power ascension, the measured MSL data may challenge the Level 1 Limit Curve in specific frequency bands. If a measurement exceeds the Level 1 Limit Curve, a reduction in power to the previously acceptable power level is required per license conditions. If a measurement exceeds the Level 2 Limit Curve, the plant shall hold at the current power level and re-evaluate the dryer loading and structural response. Challenges to the Limit Curve in specific frequency bands represent an incremental change in stress. Based on the measured plant data and projections of adjusted peak stress as described in this report, adjustments in the Limit Curves will be made and further power ascension can occur. Adjustments to the Limit Curves based on this report and assuring the measure MSL data does not exceed the adjusted curves will ensure that dryer alternating calculated stress amplitude does not exceed the Level 1 acceptance criterion, 13,600 psi.

This report provides the process steps for

1. Resolving discrepancies for cases in which frequency peaks exceed the limit curve for MSL strains, (Enclosure 1 of Reference [2], License Condition 2.C.(36)(a)4. for SSES Unit 1 and Enclosure 2 of Reference [2], License Condition 2.C.(20)(a)4. for SSES Unit 2)
2. Updating the SSES Unit 1 and 2 MSL limit curves during power ascension testing. (Enclosure 1 of Reference [2], License Conditions 2.C.(36)(b)3., 2.C.(36)(b)4., 2.C.(36)(b)5., and 2.C.(36)(b)8. for SSES Unit 1 and Enclosure 2 of Reference [2], License Conditions 2.C.(20)(b)3., 2.C.(20)(b)4., 2.C.(20)(b)5., and 2.C.(20)(b)8. for SSES Unit 2).

2. BASIS FOR UPDATING THE SUSQUEHANNA MSL LIMIT CURVES

Reference [1] used [[

]] The F-factor method was first used at Vermont Yankee Nuclear Power Station [3] to project the change in dryer stress based on the change in the MSL strain gage data, assess the impact to the dryer fatigue margin, and to recalculate the MSL limit curve factor. This section discusses the theory and application of this methodology to the SSES dryers.

2.1 F-Factor Method

The total stress intensity of the limiting (lowest margin) dryer component is the algebraic sum of the stress intensities over each frequency band.

$$S_t = S_1 + S_2 + S_3 + \dots + S_n \quad (1)$$

Where S_t is the peak stress intensity and S_1, S_2, \dots, S_n is the peak stress in each frequency band.

The contribution of the peak stress in any given frequency band is given by S_n , and can be determined by notch filtering the time domain data for a given frequency band and recalculating the stress intensity. The term $S(t-1)$, for frequency band 1, is defined by:

$$S(t-1) = 0 + S_2 + S_3 + \dots + S_n \quad (2)$$

where the contribution over frequency band 1 has been filtered out using the notch filter. Therefore the S_1 contribution can be calculated as:

$$S_1 = S_t - S(t-1) \quad (3)$$

This process can then be repeated over each of the frequency bands to generate the peak stress contribution from each band, S_n .

The pressure data in the MSLs, steam dome, and the dryer response are [[

]] The acoustic models and FE models used are linear. Therefore, if long periods of [[

]]

Assume that [[

]].

(4)

[[

]].

(5)

[[

]].

(6)

[[

]]

Reference [1] provided revised MSL limit curves for the SSES steam dryer power ascension test program. In developing the revised limit curves, averaged signals from the eight MSL monitoring locations were collected along with synchronous dryer test data during the SSES

Unit 1 power ascension to 94.4% EPU power. In development of the Reference [1] MSL limit curves, [[

]] The

MSL limit curves were then established by factoring the MSL baseline PSD curves by the square of a limit curve factor (LCF). The LCF represents the ratio of the dryer fatigue endurance limit stress, 13,600 psi, over the projected dryer stress for the associated test condition after adjustment for bias and uncertainty.

$$MSL\ Limit\ Curve(PSD) = (Baseline\ MSL\ Strain\ Gage\ PSD\ curve) * (LCF^2) \quad (7)$$

$$Where: LCF = \frac{13,600}{Peak\ Stress} \quad (8)$$

The peak stress in Equation (8) represents the peak stress intensity from the results of the FE analysis of the steam dryer multiplied by the stress bias and the total stress uncertainty.

$$Peak\ Stress\ (psi) = (Peak\ Stress\ Intensity\ from\ FE\ analysis) * (BiasFactor + Uncertainty) \quad (9)$$

In Equation (9) the uncertainty term is the [[

]]

The BiasFactor in Equation (9) is a [[

]] in Equation (6). The bias is expressed as the BiasFactor minus 1.

Table 5 in Reference [1] includes an example of the calculated bias for one component and load case.

For the first phase of the SSES power ascension to EPU conditions, the Unit 1 dryer was fully instrumented. Therefore, [[

]] As discussed at the beginning of this section, the original application of the F-factor method, with Vermont Yankee Nuclear Power Station, was to project the change in dryer stress based on the change in the MSL strain gage data, assess the impact to the dryer fatigue margin, and to recalculate the MSL limit curve factor.

The next phase of SSES power ascension testing will rely on MSL data for confirming the structural qualification of the steam dryer for flow-induced vibration (FIV). As described in Reference [1], there was synchronous MSL and dryer data collected on SSES Unit 1 in 2008 and MSL data collected on SSES Unit 2 in 2007. The two plants have almost identical acoustic signatures. The change in the projected dryer response and peak stress [[

]] (10)

[[

]] (11)

[[

]]

The MSL pressure based PSDs $\left(\frac{PSI_{RMS}^2}{Hz}\right)$ are derived from the MSL strain based PSD $\left(\frac{\mu ERMS^2}{Hz}\right)$ by factoring the strain based PSD by the square of the pressure to microstrain ratio at each monitoring location. This conversion is shown in Equation (12).

$$\frac{P(i)}{\varepsilon} = E * \left[\left(\frac{r_o}{(r_o - t)} \right)^2 - 1 \right] / (2 - \nu) \quad (12)$$

Where

- $P(i)$ (psi) = Pressure at monitored location i ,
- ε (strain) = Measured hoop strain at monitored location,
- E (psi) = Modulus of elasticity of the pipe at the monitoring location at operating temperature,
- r_o (inches) = The average pipe outer radius at the monitoring location,
- t (inches) = The average pipe thickness at the monitoring location, and
- ν (dimensionless) = Poisons Ratio.

2.2 [[]] Method

In the Limit Curve adjustment, the LCF will be determined by both the F-factor approach and a [[]]. The more limiting LCF is then employed. The [[]]

]]

Therefore, it is assumed the same relation follows [[]]

]]

The [[]]

]]

(13)

[[
]]

As with the F-factor method, the acoustic and structural model is linear and therefore a

[[
]] (14)

[[
]] (15)

[[
]] (11)

[[

]]

(16)

3. MODEL PEAK STRESS, STRESS PSDs, STRAIN PSDs, and F-FACTORS

The stress results from the GEH finite element stress analysis of the as-fabricated dryer [4] were used in developing the MSL limit curves in Reference [1]. From the nine load step cases analyzed, [[

]] The peak stress values for the high stress components and nine load cases are presented in Table 3-1 of Reference [5]. This FIV stress analysis was based on the Acoustic Circuit Model (ACM) load definition using steam line data under Main Steamline Isolation Valve (MSIV) closure conditions.

The time history stress data from the most highly stressed components was [[

]] the F-factors.

Consistent with the dryer acceptance limits [5], the [[

]] These are presented in Tables 4a and Table 4b of Reference [1]. The [[

]]

The F-Factor method (Section 2.1) will use the [[

]] used in Reference [1]. In Equation (4), to determine the [[

]]

The F-factor (or [[]]) stress adjustment methods are more effective when there is a close match in the measured and predicted dryer response. The dryer analysis must include minimal excitation and response in the factored frequency bands. Therefore stress adjustments were also performed with a supplemental acoustic load definition and FE structural analysis. The plant input to the acoustic analysis was based on SSES Unit 1 dryer data from test condition 3D (approximately 3733 MWt reactor power). The acoustic loads were developed with the model described in References [6] and [7]. The loading and dryer response indicates a much better match to the measured response. The model has improved sensitivity at both high and low frequency bands.

The supplemental analysis FE model was again run with [[

]] There were nine time-step sensitivity cases used: M10, M75, M5, M25, Nom, P25, P5, P75, and P10. The LCF assessment was done [[

]]

The supplemental analysis FE model was updated to improve the dynamic characteristics. This included more detailed modeling [[

]] as described in Reference [6].

Tables 3-1 and 3-2 include the revised [[]] that will be used with the supplemental analysis adjusted stress and LCF assessments. As in Reference [1], the [[

]] This indicates that the model is providing an ample response in all frequency bands. The one exception is around [[]] SSES Test Condition 3D conservatively includes the highest [[

]]

The [[]] used in Reference [1] have not changed. The [[]] for the Reference [1] analysis, [[]] in the limit curve adjustment calculation. This will be used for both the evaluations based on the Reference [1] analysis and the supplemental FE analysis based on the Reference [6] and [7] model. The section below explains why the [[]] is applicable to the supplemental FE analysis based on the Reference [6] and [7] model.

[[]]

[[]] The adjusted stress is increased by multiplication by the [[]] and the instrument uncertainties. This revised stress will be calculated with both the F-factor and [[]]

[[]]

]]

The supplemental analysis model limit curve factor is calculated by dividing the Level 1 alternating stress acceptance criterion (13,600 psi) by the maximum adjusted combined low frequency (LF) and high frequency (HF) stress for all high stressed components and for all 9 load step cases. The more restrictive value from [[]] F-factor method will be used. The same process is repeated for the Level 2 limit curve factor using the 11,000 psi Level 2 acceptance criterion.

4. ADJUSTED BASELINE CURVES

The first step in the recalculation of the peak dryer stress intensity and the subsequent determination of revised limit curve factors is to collect strain gage data at the power ascension test condition. Time history data of greater than 100 seconds at steady state conditions is to be collected for each of the eight strain gage monitoring locations. Each monitoring location is to have the strain gage data averaged and then filtered to remove electrical noise (60 Hz electrical noise and harmonics as well as recirculation pump motor frequency noise and harmonics) as well as the VPF signal. The time history data are to be converted to [[

]]

These processed PSD data will be used to define eight [[

]] consistent with the process used in Reference [1].

The eight PSD curves will be [[

]] The original baseline curves are the baseline curves provided in Reference [1], and correlate to the measured dryer strain for Test Condition 3D.

The PS values for all eight monitoring points will be [[

]] The [[]] must coincide with those shown in Table 2 of Reference [1] and Table 3-1 in this document. For each [[

]]

As depicted in Figures 2 and 3 of Reference [1], the SSES Unit 1 and Unit 2 MSLs have very similar acoustic signals. There are minor differences in pipe thickness and signal in regions with low amplitude. PPL will also be replacing all gages on Unit 2 during the outage prior to power ascension above 3489 MWt. At approximately 3489 MWt (Unit 2) and subsequent test points at steady power, PPL will collect steam line data and calculate the adjusted peak stress and revised limit curve factor as necessary, retaining the baseline limit curve corresponding to the test condition compared to the FE model.

Consistent with Reference [1], the original dryer finite element model stress results of Reference [4] will be evaluated with the F-factor method. For the supplemental analysis model described in Section 3 of this report, limit curve factors will be calculated with both the F-factor [[]]. The most limiting LCF from the three evaluations is used for revising the limit curves; the F-factor approach based on the Reference 1 analysis and with both the F-factor and [[]]] with the supplemental analysis.

5. REVISED LIMIT CURVES

Revised limit curves are determined by factoring the adjusted baseline limit curve by the Level 1 and Level 2 limit curve factors. The limit curves are based [[]]

]]

6. CONCLUSIONS

PPL will monitor the MSL strain gages during power ascension testing above 3489 MWt (Unit 2) and 3733 MWt (Unit 1) for increasing pressure fluctuations in the steam lines in accordance with Unit 2 license condition 2.C.(20)(a) and Unit 1 license condition 2.C.(36)(a). If resonance frequencies are identified above acceptable levels PPL will stop power ascension and re-evaluate the dryer loading and structural response. The re-evaluation of dryer loading and structural response will be performed in accordance with this report methodology.

Assuring that the Level 1 acceptance limit, dryer alternating calculated stress amplitude does not exceed 13,600 psi, will minimize the potential for fatigue damage to the PPL replacement dryer. Maintaining the measured MSL response below the Level 1 Limit Curve assures that the Level 1 acceptance criteria does not exceed 13,600 psi. During plant power ascension the measured MSL data may challenge the Level 1 Limit Curve in specific frequency bands. If a measurement exceeds the Level 1 Limit Curve, a reduction in power to the previously acceptable power level is required per license conditions. If a measurement exceeds the Level 2 Limit Curve, the plant shall hold at the current power level and re-evaluate the dryer loading and structural response. Challenges to the Limit Curve in specific frequency bands represent an incremental change in stress. Based on the measured plant data and projections of adjusted peak stress as described in this report, adjustments in the Limit Curves will be made and further power ascension can occur. Adjustments to the Limit Curves based on this

report and assuring the measure MSL data does not exceed the adjusted curves will ensure that dryer alternating calculated stress amplitude does not exceed 13,600 psi.

7. REFERENCES

- [1] “Revised Susquehanna Replacement Steam Dryer Limit Curves – Main Steam Line Mounted Instrumentation”, 0000-0096-5766-P-R1, February 2009.
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- [3] Letter, Entergy to USNRC, “Vermont Yankee Nuclear Power Station Report on the Results of Steam Dryer Monitoring,” BVY 06-056 (Docket No. 50-271, TAC No. MC0761), dated June 30, 2006.
- [4] “Susquehanna Replacement Steam Dryer Updated Stress Analysis at Extended Power Uprate Conditions,” 0000-0095-2113-P-R0, February 2009.
- [5] “Susquehanna Replacement Steam Dryer Instrumentation Acceptance Criteria – Dryer Mounted”, GE-NE-0000-0080-2994-P-R4, April 2008.
- [6] NEDC-33408P, “Licensing Topical Report ESBWR Steam Dryer – Plant Based Load Evaluation Methodology”, February 2008
- [7] NEDC-33408P-Supplement 1, “Licensing Topical Report ESBWR Steam Dryer – Plant Based Load Evaluation Methodology Supplement 1”, October 2008