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Subject: **Response to Portion of NRC Request for Additional Information Letter No. 67 Related to ESBWR Design Certification Application – Mechanical Systems and Components – RAI Number 3.9-144.**

Enclosure 1 contains GHNE's response to the subject NRC RAI transmitted via the Reference 1 letter.

If you have any questions or require additional information regarding the information provided here, please contact me.

Sincerely,

Kathy Sedney for

James C. Kinsey
Project Manager, ESBWR Licensing

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NRO

References:
1. MFN 06-378, Letter from U.S. Nuclear Regulatory Commission to David Hinds, *Request for Additional Information Letter No. 67 Related to the ESBWR Design Certification Application*, October 10, 2006

Enclosure:
1. MFN 07-325, Response to Portion of NRC Request for Additional Information Letter No. 67 Related to ESBWR Design Certification Application – Mechanical Systems and Components – RAI Number 3.9-144.

cc:	AE Cubbage	USNRC (with enclosures)
	GB Stramback	GHNE/San Jose (with enclosures)
	BE Brown	GHNE/ Wilmington (with enclosures)
	eDRF	0000-69-0521

Enclosure 1

MFN 07-325

Response to a Portion of NRC Request for Additional Information Letter No. 67 Related to ESBWR Design Certification Application Mechanical Systems and Components

RAI Number 3.9-144

NRC RAI 3.9-144

A. Describe the power ascension plan for the ESBWR that includes the following aspects:

(a) For initial startup, plant data at the ESBWR will be collected from instrumentation mounted directly on the steam dryer at significant locations (including the outer hood and skirt, and other potential high stress locations) to verify that the stress on individual steam dryer components is within allowable limits during plant operation.

(b) The instrumentation directly mounted on the steam dryer will provide sufficient information to perform an accurate stress analysis of all steam dryer components, and will include pressure sensors, strain gages, and accelerometers.

(c) The main steam lines in the ESBWR will be instrumented to collect data to determine steam pressure fluctuations in order to identify the presence of acoustic resonances and to allow the analysis of those pressure fluctuations to calculate steam dryer loading and stress.

(d) The direct steam dryer data will be used to calibrate the MSL instrumentation and data analysis prior to the removal or failure of the steam dryer instrumentation.

(e) The steam, feedwater, and condensate lines and associated components, including safety relief valves and power-operated valves and their actuators, will be instrumented to measure vibration during plant operation to demonstrate that short-term and long-term qualification limits are not exceeded for the piping and individual components.

B. Describe the ESBWR startup test procedure that includes the following:

(a) the stress limit curve to be applied for evaluating steam dryer performance;

(b) specific hold points and their duration during power ascension with sufficient time intervals for interaction with NRC staff during power ascension;

(c) activities to be accomplished during hold points that are of sufficient duration to accomplish those activities;

(d) plant parameters to be monitored;

(e) inspections and walkdowns to be conducted for steam, feedwater, and condensate systems and components during the hold points;

(f) the method to be used to trend plant parameters;

(g) acceptance criteria for monitoring and trending plant parameters, and conducting the walkdowns and inspections; and,

(h) actions to be taken if acceptance criteria are not satisfied.

GE Response

Response to RAI 3.9-144 A (a) through (d):

The steam dryer instrumentation and power ascension plan is described in Subsection 3L.4.6 of DCD, Tier 2, Appendix 3L. Details regarding the confirmation of the ESBWR steam dryer load definition and stress analysis during initial power ascension will be provided in a future reference report: General Electric Company, "Steam Dryer - Instrumentation and Power Ascension Monitoring," NEDC-33314P, Class III (Proprietary), and NEDO-33314, Class I (Non-Proprietary). See RAI 3.9-58 Response.

Response to RAI 3.9-144 A (e):

The response to RAI 3.9-20 includes the methodology to develop the startup criteria and the required instrumentation for these piping systems and the valve operators. These criteria will demonstrate that short-term and long-term qualification limits are not exceeded.

The instrumentation for steam, feedwater and isolation condenser piping systems are listed in the following table and will be used to measure vibration during plant operation to demonstrate that short-term and long-term qualification limits are not exceeded for the piping and individual components. The information will be included in the startup test documentation.

The following gages are required for each line inside the containment (Note 1). The measurements for main steam acoustic load are not included. (Note 2).

Pipe lines	**Gage type**	**Location**	**Number of gages**	**Remarks**
Each Main steam (2 lines needed, line 1&2)	Displacement (LVDT)	MS pipe, lateral directions	4	Test specifications specify exact locations
	Accelerometers (Acc)	SRV valve (2 locations, X,Y and Z)	6	Same as above

Pipe lines	**Gage type**	**Location**	**Number of gages**	**Remarks**
	Accelerometers (Acc)	MSIV valve (2 locations)	6	Same as above
	Strain gages (SG)	SRV branch (2 locations)	4	Same as above
Each Feedwater System (Note 3)	Displacement (LVDT)	FW pipe (2 locations)	6	Same as above
	Strain gages (SG)	FW pipe (2 locations)	6	Same as above
Isolation Condenser (Condensate line, one system selected) (Note 4)	Displacement (LVDT)	Condensate line at RPV 160 degrees	3	Test specifications specify exact locations
	Accelerometers (Acc)	Condensate lines at RPV 160 degrees. Normally closed valve operators	6	Same as above
	Strain gages (SG)	Condensate line at RPV 160 degrees	3	Same as above
Isolation Condenser (Steam line)	Displacement (LVDT)	Steam lines at RPV 135 degrees	3	Test specifications specify exact locations
	Accelerometers (Acc)	Steam lines at RPV 135 degrees Normally opened valve operators	3	Same as above

Note 1 :The instrumentation set up will insure that the piping displacements and the vibration stresses of the piping system are within the ASME allowable limits. Detail gage setup and number of gages may be changed during the actual design process. The gages for all other systems, such as condensate piping of the Isolation Condenser system, will be instrumented after the stress analyses are completed and used to determine the most critical locations.

Note 2 : The instrumentation does not include the strain gage setup for the dryer to measure the acoustic resonance in the main steam pipe due to the SRVs. These measurements use pairs of strain gages in the circumferential direction of the pipe. The gages are located before and after the valves. The gages are located on the pipe at locations free from stress concentrations.

Note 3 For FW pipe outside the containment, hand held vibration instrumentation will be used to measure the piping and valve operator vibration during walk downs and at startup hold points.

Note 4 The valve operability tests are not in the scope of this table.

Response to RAI 3.9-144 B (a):

The ESBWR start up test program is discussed in Section 3L.5 of DCD, Tier 2, Appendix 3L.

The fatigue analysis performed for the ESBWR steam dryer will use a fatigue stress limit of 13.6 ksi. For the outer hood component, which is subjected to higher pressure loading in the region of the main steam lines, the fatigue stress limit will be 10.8 ksi. The higher stress limit is justified because the dryer is a non-safety component, performs no safety functions, and is only required to maintain its structural integrity (no loose parts generated) for normal, transient, and accident conditions.

Response to RAI 3.9-144 B (b):

The ESBWR startup test program schedule, as outlined in DCD2 Subsection 14.2.7, consists of three testing phases: initial fuel loading and open vessel testing, testing during nuclear heatup to rated temperature and pressure (less than 5% power), and power operation testing from 5% to 100% rated power. The power operation testing phase is further divided into three power ascension test conditions; low power testing at less than 25% power, mid-power testing up to about 75% power, and high power testing up to rated power.

Each of these five testing plateaus has a window for testing and a non-testing interval when operating conditions are not increased. Testing windows will be scheduled to include time to perform all required testing. Following completion of testing in each window, test data and results are reviewed, evaluated and approved by the startup organization as described in Subsection 14.2.2. Some tests late in the window will have their reviews, evaluations and approvals completed during the subsequent non-testing interval.

During these non-testing intervals, the plant could be held at the last satisfactorily tested power level or may recommence startup and power ascension to return to that level if the final test involved a scram. Activities taking place during these periods include: final test result approvals, approval of overall test phase results and authorization to proceed with the next plateau's testing by the licensee. These non-testing periods between the test plateaus extend from the plateau testing completion milestone to the authorization to continue startup testing/power ascension milestone, and may be a few days in length.

It has been the convention that licensees maintain communications with the NRC during their approval process and consult with the NRC prior to their authorization to continue the power ascension testing. As the startup test schedule, startup administrative manual, licensee's overall results approval and power ascension authorization processes have not been prepared, the durations of these non-testing periods are currently not known. Also, details of the licensee-NRC communication protocols are not available at this time.

These non-testing intervals would be one form of hold point in the startup test program schedule in which all testing in that plateau is reviewed and approved, and authorization to proceed with the power ascension is granted. All NRC staff interactions are anticipated to be satisfied or mutually agreed upon resolutions put in place before the licensee authorizes the continuation of startup testing.

The other hold point would be one during the plateau's testing sequence, as indicated in DCD2 Subsection 14.2.7. Examples could include: the satisfactory review and approval of an earlier piping system's flow induced vibration test results as a prerequisite to a later transient test where the piping vibration of the same system is being evaluated, or necessary control system tuning that has to be performed before a subsequent test where its results are affected by the control system performance.

Response to RAI 3.9-144 B (c):

In the first hold point, because review and approval of all the tests in a test phase (re: DCD2 Table 14.2-1), overall test phase results approval, and power ascension authorization are required to be completed before the non-testing interval ends, its duration will be adjusted to accommodate these efforts. In the latter, other plateau testing would continue where the test conditions and prerequisites are met. Plus, tests that were performed earlier in the test plateau sequence could have their results reviewed and approved.

During the non-testing periods, operations and startup personnel will continue to monitor the plant equipment and parameters. Maintenance activities necessary to support continuing operations and startup testing (e.g., recharge demineralizers, calibrate instrumentation, fine-tune control systems, replace temporary sensors) would be performed. Any of these activities that are deemed essential for the startup testing/power ascension will be scheduled for completion prior to the power ascension authorization being given.

Response to RAI 3.9-144 B (d):

During the testing and non-testing periods the full complement of power plant parameters will continue to be monitored by operations personnel. Startup personnel will also continue to monitor plant systems under startup testing and temporary startup test sensor systems. Additionally, the startup organization will support operations' plant data and system performance reviews.

Response to RAI 3.9-144 B (e):

Startup personnel and equipment specialists will closely monitor these systems through power ascension and startup testing. During non-testing intervals, the test personnel periodically monitor these systems and support operations plant monitoring. Testing on these systems includes: overall system and equipment performance, related control system testing, and transient testing related to potential equipment failures and plant trips. Operations will continue to make their regular walkdowns of the accessible areas of the plant recording remote instrument data and observing operating equipment throughout the startup testing period.

Response to RAI 3.9-144 B (f):

The principle means of trending plant parameters is via the plant process computer. Because data is available to this computer system from plant-wide instruments, data can be recorded and plotted, it will be a key tool in gathering, evaluating and trending plant parameters. Trending may also be performed on other computer systems, with data from: the process computer, other plant computers, test data acquisition systems, and operator round logs. These other systems could be either on site or off, be dedicated to specific functions, and be available to technical experts to support evaluation. All plant parameter trends applicable to test procedure acceptance criteria and supporting result evaluations will be available in the on-site test records for the licensee's overall test phase results approval.

Response to RAI 3.9-144 B (g):

Some plant parameters will be compared against acceptance criteria that are derived from Technical Specifications, system design limitations and equipment protective settings. Other acceptance criteria for the normal operating values will be determined from plant heat balances, system operating models and experience gained from preoperational and startup testing. In addition, monitored and trended plant parameters can be compared against the operating and testing experience from other BWR plants, on similar power plant systems, and with industry operating experience.

Individuals knowledgeable in the systems, structures and components being tested will perform these walkdowns and inspections. Acceptance criteria are reviewed before hand and results considered that are both the expected conditions and unacceptable findings. In addition, any unexpected observations, like signs of water or steam, unusual sounds, are reported for further evaluation. Operations walkdowns would be performed with procedural guidance on acceptance criteria for the remote data being collected and equipment being inspected.

Response to RAI 3.9-144 B (h):

Acceptance criteria are categorized; Level 1, Level 2 or Level 3, and actions taken when a criterion is not satisfied are prescribed by their categorization.

Level 1

A Level 1 criterion relates to the value of process variables assigned in the design or analysis of the plant and component systems or associated equipment. Violation of these Level 1 criteria may have plant operational or plant safety implications. Therefore, if a Level 1 test criterion is not satisfied, the plant must be placed in a suitable hold condition that is judged to be satisfactory and safe based on the results of prior testing. Plant operating or test procedures or Technical Specifications may guide the decision on the direction to be taken.

Resolution of the problem must immediately be pursued by appropriate equipment adjustments or through engineering support, including offsite personnel if needed. Following resolution, the applicable test portion must be repeated to verify that the Level 1 requirement is ultimately satisfied. A description of the problem resolution shall be included in the report documenting the successful test.

Level 2

Level 2 criteria are specified either as:

a) key plant, system or equipment performance requirements that are consistent with the plant contract specification, individual system or equipment design specification values or requirements for the measured response, or

b) the expected plant response predicted by best estimate computer code and the desired trip avoidance margins as applicable to plant transient testing.

If all Level 2 criteria requirements in a test are ultimately satisfied, there is no need to document a temporary failure in the test report unless there is an educational benefit involved. Following resolution, the applicable test portion must be repeated to verify that the Level 2 criteria requirement is satisfied.

If a Level 2 criteria requirement is not satisfied after a reasonable effort, then the cognizant design and engineering organization may choose to document the results with a full explanation of their recommendations. Therefore, all Level 2 criteria requirements may not be satisfied provided that overall system performance is deemed to be acceptable based upon the design and engineering's recommendations. The specific action(s) as required in dealing with the criteria violations and other test exceptions or anomalies shall be consulted at the site based upon the startup administrative manual.

Level 3

Level 3 criteria are associated with specifications of the expected or desired performance of individual components or inner control loop transient performance. Meeting Level 3 criteria helps assure that overall system and plant response requirements are satisfied. Therefore, Level 3 criteria are to be viewed as highly desirable rather than required to be satisfied. Good engineering judgment is necessary in the application of these rules.

Because overall system performance is a mathematical function of its individual components, one component whose performance is slightly less than specified can be accepted provided that a system adjustment elsewhere will positively overcome this small deficiency. Large deviations from Level 3 performance requirements are not allowable.

If a Level 3 criterion requirement is not satisfied, the subject component or inner loop shall be analyzed closely. However, if all Level 1 and Level 2 criteria are satisfied, then it is not required to repeat the transient test to satisfy the Level 3 performance requirements. The occurrence of this Level 3 criterion failure shall be documented in the test report.

DCD Impact

Response to RAI 3.9-144 A (a) through (d):

DCD Tier #2 rev. 2, Section 3L.6 was revised as noted in the attached markup of DCD2 rev. 3.

Response to RAI 3.9-144 A (e):

No DCD changes will be made in response to this RAI.

Response to RAI 3.9-144 B (a):

DCD2 rev. 2, Subsection 3.9.2.3 and Appendix 3L.5.5.2 were revised as noted in the attached markup of DCD Tier #2 rev. 3.

Response to RAI 3.9-144 B (b) through (h):

No DCD changes will be made in response to this RAI.

anchorage devices are designed in accordance with the requirements of the Code, Subsection NF, or ANSI/AISC - N690 and ACI 349.

Dynamic design data are provided in the form of acceleration response spectra for each floor area of the equipment. Dynamic data for the ground or building floor to which the equipment is attached are used. For the case of equipment having multiple supports with different dynamic motions, an upper bound envelop of all the individual response spectra for these locations is used to calculate maximum inertial responses of items with multiple supports.

Refer to Subsection 3.9.3.5 for additional information on the dynamic qualification of valves.

Supports

Subsections 3.9.3.7 and 3.9.3.8 address analyses or tests that are performed for component supports to assure their structural capability to withstand the seismic and other dynamic excitations.

3.9.2.3 Dynamic Response of Reactor Internals Under Operational Flow Transients and Steady-State Conditions

The major reactor internal components within the vessel are subjected to extensive testing, coupled with dynamic system analyses, to properly evaluate the resulting flow-induced vibration phenomena during normal reactor operation and from anticipated operational transients.

In general, the vibration forcing functions for operational flow transients and steady-state conditions are not predetermined by detailed analysis. Special analysis of the response signals measured for reactor internals of many similar designs is performed to obtain the parameters, which determine the amplitude and modal contributions in the vibration responses. This study provides useful predictive information for extrapolating the results from tests of components with similar designs to components of different designs. This vibration prediction method is appropriate where standard hydrodynamic theory cannot be applied due to complexity of the structure and flow conditions. Elements of the vibration prediction method are outlined as follows:

- Dynamic modal analysis of major components and subassemblies is performed to identify vibration modes and frequencies. The analysis models used for Seismic Category I structures are similar to those outlined in Subsection 3.7.2.
- Data from previous plant vibration measurements are assembled and examined to identify predominant vibration response modes of major components. In general, response modes are similar but response amplitudes vary among BWRs of differing size and design.
- Parameters are identified which are expected to influence vibration response amplitudes among the several reference plants. These include hydraulic parameters such as velocity and steam flow rates and structural parameters such as natural frequency and significant dimensions.
- Correlation functions of the variable parameters are developed which, multiplied by response amplitudes, tend to minimize the statistical variability between plants. A correlation function is obtained for each major component and response mode.

- Predicted vibration amplitudes for components of the prototype plant are obtained from these correlation functions based on applicable values of the parameters for the prototype plant. The predicted amplitude for each dominant response mode is stated in terms of a range, taking into account the degree of statistical variability in each of the correlations. The predicted mode and frequency are obtained from the dynamic modal analyses.

The dynamic modal analysis forms the basis for interpretation of the initial startup test results (Subsection 3.9.2.4). Modal stresses are calculated and relationships are obtained between sensor response amplitudes and peak component stresses for each of the lower normal modes. The allowable amplitude in each mode is that which produces a peak stress amplitude of ±68.95 MPa (±10,000 psi). For the steam dryer and its components, a higher allowable peak stress limit is used as explained in the following paragraphs.

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Vibratory loads are continuously applied during normal operation and the stresses are limited to ±68.95 MPa (±10,000 psi), with the exception of steam dryer, in order to prevent fatigue failure. Prediction of vibration amplitudes, mode shapes, and frequencies of normal reactor operations are based on statistical extrapolation of actual measured results on the same or similar components in reactors now in operation.

Extensive predictive evaluations have been performed for the steam dryer loading and structural evaluation. These evaluations are described in Section 3L.4 of DCD Tier 2 Appendix 3L. The fatigue analysis performed for the ESBWR steam dryer will use a fatigue limit stress amplitude of 93.7 MPa (13,600 psi). For the outer hood component, which is subjected to higher pressure loading in the region of the main steam lines, the fatigue limit stress amplitude of 74.4 MPa (10,800 psi). The higher limit is justified because the dryer is a non-safety related component, performs no safety functions, and is only required to maintain its structural integrity (no loose parts generated) for normal, transient and accident conditions.

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The dynamic loads caused by flow-induced vibration of the steam separators had been determined using a full-scale separator test under reactor conditions. During the test, the flow rate through the steam separator was 226,000 kg/hr (499,000 lbm/hr) at 7% quality. This is higher than the ESBWR maximum separator flow of 99,800 kg/hr (220,000 lbm/hr). Test results show a maximum flow induced vibration stress of less than 48.6 MPa (7200 psi), well below the GE acceptance criteria of 68.9MPa (10,000 psi). Thus it can be concluded that separator flow induced vibration effects are acceptable. Jet impingement from feedwater flow has no significant effect on the steam separator assembly since the separator skirt is above the feedwater flow impingement area.

3.9.2.4 Initial Startup Flow-Induced Vibration Testing of Reactor Internals

Reactor internals vibration measurement and inspection program is conducted only during initial startup testing. This meets the guidelines of Regulatory Guide 1.20 with the exception of those requirements related to preoperational testing which cannot be performed for a natural circulation reactor.

Initial Startup Testing

Vibration measurements are made during reactor startup at conditions up to 100% rated flow and power. Steady state and transient conditions of natural circulation flow operation are evaluated.

In the ESBWR prototype plant FIV test program of the dryer assembly, accelerometers and strain gages are located directly on the skirt, drain channels, support ring and hoods (Reference 3L-7). In addition, pressure sensors are used to measure the pressure differentials between the inside and outside of the dryer hood and dryer skirt. The differential pressure fluctuation across the dryer hoods is the primary forcing function causing vibration of the upper part of the dryer structure. The differential pressure fluctuation across the dryer skirt is the primary forcing function causing the vibration of the steam dryer skirt.

A dynamic finite element model of the dryer assembly is developed using the ANSYS computer code (References 3L-3 and 3L-6). Due to the complicated geometry and the large size of the analytical model, major components may be modeled with coarse meshes such that their dynamic contributions are accounted for in the whole dryer assembly vibration responses. Separate refined dynamic finite element models of the major components are then developed to provide a high resolution of the component's response calculation.

The structural material properties and density for the dryer components at temperature are used in the model. The effect of the water on the dynamic responses is accounted for by using a direct lumped mass input. These added mass inputs include the submerged portions of the dryer skirt, drain channels, and the lower support ring.

Prior analytical models have predicted that the vibration modes are very closely spaced.

3L.5.5.1.4 Standby Liquid Control Lines

In the ESBWR prototype plant reactor, there are two standby liquid control pipes that enter the reactor vessel and are routed to the shroud. To accurately predict the vibration characteristic of the standby liquid control line, a dynamic finite element model of the entire line is developed using the ANSYS computer code. In the model the ends of the line are fixed anchor points since the lines are welded at the vessel nozzle and the shroud attachment points.

3L.5.5.2 Stress Evaluation

Maximum stress amplitude values for evaluation against allowable limits are determined from the test data and finite element models using one of three different evaluation methods. The method used for a particular component depends on the complexity of that component's vibration characteristics. All three methods yield conservatively high predictions of the maximum stress anywhere on the structure. These conservatively high stress predictions are compared against conservatively low acceptance criteria to assure that none of the components is experiencing high stress vibrations that might cause fatigue failures. Table 3L-7 lists the methods that are used for each instrumented component for the ESBWR prototype plant FIV test program. The acceptable fatigue limit stress amplitude for the reactor internals component material [68.9 MPa (10,000 psi)], with the exception of the steam dryer. The fatigue analysis performed for the ESBWR steam dryer will use a fatigue limit stress amplitude of [93.7 MPa (13,600 psi)]. For the outer hood component, which is subjected to higher pressure loading in the region of the main steam lines, the fatigue limit stress amplitude of [74.4 MPa (10,800 psi)]. The higher limit is justified because the dryer is a non-safety component, performs no safety functions, and is only required to maintain its structural integrity (no loose parts generated) for normal, transient and accident conditions.

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Method I is used for components that have many closely spaced vibration frequencies and/or closely spaced natural vibration modes distributed over a relatively narrow frequency range. The method utilizes a strain energy weighting method applied to all modes over the entire frequency range. It is applied by determining the maximum peak-to-peak (p-p) amplitude from an unfiltered time history segment. This maximum value is multiplied by a combined shape factor (derived from the strain energy weighting method) and stress concentration factors to yield the maximum stress value that could be expected to be found anywhere on the structure. This value is then compared against the acceptable fatigue limit stress amplitude for the component and material.

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Method II is used for components that have many closely spaced vibration frequencies and/or closely spaced natural vibration modes that are unevenly distributed over several frequency ranges. The method is very similar to Method I, except that it is applied over several separate frequency bands. The maximum stress amplitude values for each frequency band are then added together absolutely to yield a conservatively high value for the overall maximum stress amplitude that could be found anywhere on the structure. This value is then compared against the acceptable fatigue limit stress amplitude for the component and material.

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Method III is used for components that have relatively few, distinct dominant natural modes that can be easily identified and matched to the modes predicted by the finite element models. This method utilizes a mode shape factor for each vibration mode that relates the stress at the sensor location to the stress at the maximum stress location for that mode. Appropriate stress concentration factors are also considered in this process. Response spectra are generated from the sensor output, from which the equivalent maximum p-p strain amplitude for each mode can be determined. The mode shape and stress concentration factors are applied mode by mode to determine the maximum stress amplitude associated with each mode. Then the maximum stress amplitudes from each of the modes are added together absolutely to yield a conservatively high maximum overall stress amplitude for the structure. This value is then compared against the acceptable fatigue limit stress amplitude for the component and material.

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All three methods have identical initial steps to obtain mode shape factors for each natural mode. The first five steps for all three methods are as follows (Note: The evaluation method described here relates to strain gages. Similar steps are used for accelerometers used in their displacement mode and for LVDTs. The example assumes a maximum allowable stress amplitude for the material of [68.9 MPa (10,000 psi)] for the purposes of illustration):

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(1) The dynamic finite element model of each instrumented component is used to predict the natural vibration modal displacement, frequency and stress for each vibration response mode. Specifically, the computer model provides the following results for each mode:

ω_i = Natural frequency for vibration mode i

$\{\phi\}_i$ = Mass normalized displacement mode shape for vibration mode i.
(Normalized such that the generalized mass, $\{\phi\}_i^T[M]\{\phi\}_i$, is unity, where [M] is the mass matrix.)

$\{\sigma\}_i$ = Normalized stress distribution for vibration mode i.
(The stress corresponding to the mass normalized mode shape, $\{\phi\}_i$)

The theory and methods for calculation of these parameters may be found in text books on the subject of basic vibration analysis, such as Reference 3L-4.

(2) For each vibration mode, stress concentration factors are applied at weld locations and regions with high stress gradient. From this information, the maximum stress intensity location and value is determined for each vibration mode.

$$\sigma_{i,\max} = Max\{SCF_i \cdot \sigma_i\} \text{ considered over the entire structure}$$

where

SCF_i = Stress concentration factor at some location

σ_i = Normalized stress intensity at the same location

$\sigma_{i,\max}$ = Normalized maximum stress intensity for mode i

(3) From the stress distribution of Step 1, a mode shape factor is derived relating the stress at the sensor to the stress at the maximum stress location as determined in Step 2:

$$\mathrm{MSF}_i = \frac{\sigma_i\,\text{(at maximum stress intensity location)}}{\sigma_{i,\mathrm{sensor}}}$$

where

MSF_i = Mode shape factor

$\sigma_{i,sensor}$ = Normalized stress at sensor location for vibration mode i

(4) The mode shape factor from Step 3 and the maximum allowable stress amplitude for the material [68.9 MPa (10,000 psi)] are used to determine the maximum allowable stress value at the sensor location for each mode.

$$\sigma_{i,sensor,allowed} = \frac{68.9\ MPa}{(MSF_i)\cdot(SCF_i)}$$

where

$\sigma_{i,sensor,allowed}$ = Maximum allowed zero to peak stress amplitude at sensor location for vibration mode i (stress amplitude at sensor when maximum stress amplitude in structure is 68.9 MPa)

(5) The allowable strain for mode i ($\varepsilon_{i,\mathrm{allowed}}$) is then calculated from this maximum allowed stress amplitude at the sensor location:

$$\varepsilon_{i,allowed} = \frac{\sigma_{i,sensor,allowed}}{E}$$

where

E = Young's modulus [e.g., 1.862 x 105 MPa (27.0 x 106 psi) at 160°C]

This equation is for uniaxial stress components. A similar, but more complex procedure will be used for biaxial stress structures such as the dryer skirt, drain channel and hood.

At this point, Methods I and II diverge from Method III.

3L.5.5.2.1 Methods I and II

The next two steps are identical for Methods I and II.

(6) A weighting factor is determined by the strain energy method, which begins by obtaining the solution to the following equation based on the expected forcing function:

$$\{U\} = q_1\{\phi\}_1 + q_2\{\phi\}_2 + \ldots = \sum_{i=1}^{N} q_i\{\phi\}_i$$

where

{U} = A vector representing the displacement response of the structure when subjected to the expected forcing function shape. This displacement response to an input forcing function is calculated from the finite element model on the computer.

$\{\phi\}_i$ = Mass normalized mode shape for vibration mode i. Mode shapes were determined from the modal analysis of the finite element model on the computer. The modes shapes are normalized such that the generalized mass, $\{\phi\}_i^T[M]\{\phi\}_i$, is unity (where [M] is the mass matrix).

q_i = Mode i response, dependent on load distribution. These coefficients are calculated from the previously calculated {U} and $\{\phi\}_i$ using formulas derived from the generalized Fourier Theorem.

This is an application of the generalized Fourier Theorem, which establishes that a displacement function such as {U} can be represented by a linear sum of the eigenfunctions, $\{\phi\}_i$. The theory and methods for calculation of these coefficients may be found in any good text book on the subject of basic vibration analysis, such as Reference 3L-4.

(7) The strain energy contribution, e_i, for each mode is then calculated:

$$e_i = \frac{1}{2} \cdot q_i^2 \cdot \{\phi\}_i^T \cdot [K] \cdot \{\phi\}_i$$

where

[K] = The structural stiffness matrix (For a more detailed explanation of the theory and calculation methods, see any good vibration analysis textbook, such as Reference 3L-4.)

The next step is similar for both Methods I and II, the only difference being that Method I will include the entire frequency range into one group, while Method II will break into several frequency ranges.

(8) Then the strain energy weighted allowable strain vibration amplitude is calculated over a given frequency range by combining the weighted strain allowable values for each mode as follows:

3L.6 REFERENCES

3L-1 General Electric Company, "ESBWR Reactor Internals Flow Induced Vibration Program – Part 1", NEDE-33259P, Class III (Proprietary), January 2006, and NEDO-33259, Class I (Non-proprietary), January 2006.

3L-2 General Electric Company, "BWR Steam Dryer Integrity", SIL 644 Revision 2, August 30, 2006.

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