# SAFETY GUIDE 20–VIBRATION MEASUREMENTS ON REACTOR INTERNALS

## A. Introduction

General Design Criterion 1 requires that structures, systems and components important to safety be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. This guide presents an acceptable method for implementing this criterion with regard to preoperational vibration testing of reactor internals (structural components inside the reactor vessel) important to safety to demonstrate that flow-induced vibrations similar in nature to those expected during operation will not cause damage. Subsequent inservice inspections to verify that these components have not been subjected to structural degradation as a result of vibration during normal reactor operation are not covered by this guide.

## B. Discussion

Reactor internals that are important to safety are designed to withstand the predicted cyclic loads due to vibration in combination with the other loads encountered during their service life. The dynamic conditions generated by the flow of the reactor coolant within the reactor vessel and reactor coolant system components are predicted analytically and in conjunction with data derived from laboratory and full-scale test programs.

The purpose of these calculations and tests is to estimate the input forcing functions which cause vibrations and to verify the vibrational response (frequency and amplitude) of the reactor internal components predicted for the prototype design. However, the analytical techniques and limited test data available, at present, are not yet adequate to predict and confirm the significant sources and levels of the input forcing functions and the associated responses of the internal components without verification by measurement.

At several nuclear power plants, the dynamic forces associated with the flow of reactor coolant have resulted in excessive vibration of some components of the reactor internals. The vibration has been sufficient to weaken (fatigue) the components and, in some cases, has resulted in their failure.

The analytical and empirical techniques which provide the initial basis for the evaluation of the effects of vibration need verification by measurement. Because of the lack of experience with vibration characteristics of various reactor configurations, and the limitations of the analytical and empirical techniques used to date, a program of vibration analysis, measurement, and inspection, is needed for each prototype design.[1] The extent of this program is dependent on the adequacy of analytical and empirical data available for a given design, as may be derived from scale tests or other prototype tests.

For reactors whose internals are similar in design of that of the vibration-tested reactor considered as the prototype, either an inspection of the reactor internals following preoperational functional testing, or the use of appropriate vibration-measuring instrumentation to detect the predominant vibratory responses observed in the prototype reactor, provides a basis for confirmation that the vibrational characteristics and their effects are not unlike that of the prototype reactor.

## C. Regulatory Position for Prototype Reactor Internals[1]

1. A vibration analysis and test program should be developed. The test program should be submitted for review by the Commission prior to the performance of the scheduled preoperational functional tests.

   The vibration testing should be conducted with the fuel elements in the core structure of the reactor internals (or with dummy elements which provide equivalent mass and flow characteristics).

[1] A prototype design of reactor internals is the first design respresentative of a group of reactors of substantially the same design, size and configuration. This group of reactors may include all those in which the variations in the parameters of operation pressure, temperature, flow conditions, coolant velocities, and pressure losses for the range of operating conditions can be demonstrated as negligible with respect to their influence upon the input vibratory functions.

Testing may also be conducted with the core structure not loaded with fuel elements provided such conditions can be demonstrated to result in vibrational characteristic which, for the purposes of the test, will yield conservative results.

The test program should include:

a. a brief description of the vibration test program, including instrumentation types and diagrams of their location, which will be used for measurement of vibration responses and those parameters which define the input forcing functions,
b. the planned duration of the test for normal operating modes to assure that all critical components are subjected to at least $10^7$ cycles of vibration,
c. the additional test duration for other than normal operating modes to assure that the number of cycles imposed on the critical components is sufficient to analyze their adequacy to withstand vibrations under these operating modes,
d. the description of different flow modes of operation and transients to which the internals will be subjected during the test,
e. the predominant response mode shapes and the estimated range of numerical values of the response of the major components of the reactor internals in terms of amplitudes and, where appropriate, the anticipated values of the paramaters which may influence the input forcing function, under those flow modes of reactor operation which are shown by the analyses to be the most critical,
f. the test acceptance criteria and the permissible deviations from these criteria, and the bases upon which these criteria were established,
g. a description of the inspection program which will be followed after the completion of the vibration tests, including the areas of reactor internals subject to examination, the method of examination, the design access provisions in the reactor internals and the specialized equipment to be employed for performing such examinations.

2. A vibration test program should be implemented during the preoperational functional testing program to measure the response[2] of the reactor internals and, where appropriate, the values of those parameters which will define the input forcing functions for the more critical modes of reactor operation. The data obtained by these measurements on reactor internals should be sufficient to verify that the cyclic stresses in the components, as determined by analyses of these data, are within the acceptable design stress limits set forth in the design specifications and applicable code requirements and that the results meet the acceptance criteria of the vibration test program.

3. The extent of the measurements should be determined, for each individual case, on the basis of the design and configuration of those structural elements of the reactor internals important to safety and their predicted behavior as determined from the vibration analyses used in their design. The type of vibration test instrumentation used, the number of measurements taken, and the distribution of measuring devices within the reactor should be adequate to detect the presence of lateral, vertical, and torsional amplitudes of vibration (e.g., beam, column, and shell modes of vibrations, as applicable to the geometry of the internals) and at sufficient locations to determine the points of predominant maximum vibratory oscillations.

4. After the reactor internals have been subjected to the significant flow modes expected during service lifetime under normal reactor operation, and other modes of reactor operation, visual and nondestructive surface examinations of reactor internals should be conducted to detect any evidence of the effects of vibrations. These examinations should be conducted preferably following removal of the internals from the reactor vessel.

   Where removal is not feasible, the examinations should be performed by means of examination equipment appropriate for in situ examination. The areas examined should include all major

[2] Frequency and amplitudes of vibration, in terms of velocities, accelerations and displacements or strains.

load-bearing elements of the reactor internals which are relied upon to retain the core structure in place, the lateral, vertical, and torsional restraints provided within the reactor vessel, those locking and bolting devices whose failure could adversely affect the structural integrity of the internals, and those critical locations on reactor internal components as identified from the vibration analyses.

5. In the event either the inspections of reactor internals reveal unacceptable defects or the results of the vibration test program fail to meet the specified acceptance criteria, a report should be prepared and submitted to the Commission for review, which includes an evaluation and a description of the corrective actions planned in order to justify the adequacy of the reactor internals design to withstand the vibrations expected in service.

6. If the test and examination program is acceptable, a summary of the results obtained from the vibration tests and inspection should be submitted to the Commission after completion of the tests. The summary should include:
   a. a description of any differences from the specified vibration tests program, instrumentation reading anomalies and instrument failures.
   b. a comparision between the measured values of vibration responses including the parameters[3] from which input forcing functions are determined and the predicted values from the analysis. This comparison should be made for those components of the reactor internals for which the acceptance criteria under C.1.f. have been established with respect to the different modes of vibration,
   c. an evaluation of measurements that exceeded acceptable limits or of observations that were unanticipated, and the disposition of such deviations.

[3]Where measurements to determine forcing functions cannot be obtained practically in all areas by means of pressure transducers (or other instruments), such values may be estimated from measured responses and from analytical and empirical results.

**D. Regulatory Position for Reactor Internals Similar to the Prototype Design**

1. The reactor internals important to safety should be subjected during the preoperational functional testing program to all significant flow modes of normal reactor operation and under the same test conditions imposed on the prototype design whose vibration analysis and tests have been accepted and approved.

   The test duration should be at least as long as that conducted on the prototype design.

2. Following completion of the preoperational functional tests, the reactor internals should be removed from the reactor vessel and visual and nondestructive examination of the reactor internals should be conducted. The areas examined should include:

   a. all major load bearing elements of the reactor internals relied upon to retain the core structure in place,

   b. the lateral, vertical, and torsional restraints provided within the vessel,

   c. those locking and bolting devices whose failure could adversely affect the structural integrity of the internals,

   d. those other locations on the reactor internal components which were examined on the prototype design,

   e. the interior of the reactor vessel for evidence of loose parts or foreign material.

3. In lieu of the visual and surface examinations of the removed reactor internals of 2. above, a vibration test program may be implemented during the preoperational functional testing program by using sufficient and appropriate vibration-measuring instrumentation to detect the predominant vibratory responses observed in the approved and accepted prototype design.

   The predominant vibratory responses to be measured should be those which, from the results of the prototype test, identify the principal characteristics and modes of vibration of the reactor internal

components, and which will permit comparison of measured responses to confirm the substantially similar vibrational behavior between the tested internals and its prototype unit, within the limits of the test acceptance criteria of the prototype design.

In the event significant dissimilarity of responses are observed for specific components, visual examinations should be performed of these components by means of appropriate examination equipment which permits in situ inspection. In all cases, the interior of the reactor vessel should be visually checked for evidence of loose parts and foreign material.

4. A summary of the inspection of D.2. above, or the results from the vibration test program of D.3. above, should be submitted to the Commission after completion of the inspection and tests, in the form of summary discussed under C.5. above, to confirm that the observed vibrational characteristics are similar to those of the prototype design. The report should include an evaluation of any observed dissimilarity of responses between the tested internals and its prototype and the corrective actions taken to confirm the acceptance of the test results.