Jet Pump Flow-Induced Vibration

ISSUE STATEMENT

Worldwide, a number of boiling water reactor plants (primarily BWR/4 and /5 designs) are experiencing jet pump degradation associated with flow induced vibration. The primary causes for jet pump degradation from flow-induced vibration are thought to be turbulent flow through the jet pumps, slip joint leakage flow instability, and pressure pulsations from pump vane passing. Jet pump degradation is generally characterized by wedge and rod wear, but one plant recently experienced substantial cracking in a jet pump riser extending 240 degrees around the circumference. The rate and severity of observed jet pump degradation is increasing. Further, the power uprates being pursued by many plants can lead to increased flow-induced vibration loads on the jet pump assembly.

DRIVERS

There are a number of factors that drive the need for timely resolution of the jet pump flow induced vibration issue, including:

Asset Management: Asset management is the primary driver associated with the management of jet pump flow-induced vibration. Jet pump degradation has become one of the most costly BWR material issues, with costs currently exceeding $20 million. Several plants have experienced wedge and rod wear even after installing clamps, auxiliary wedges or labyrinth seals. In 2008, a BWR/5 plant experienced a significant fatigue crack in a jet pump riser that resulted in several months of downtime and required a permanent repair.

Anticipated Growth in the Extent and Severity of Degradation: There is a potential for jet pump degradation issues to become more widespread as plants age. Plant uprates can exacerbate jet pump degradation if mitigation techniques are not available and implemented.

Safety Impact: The integrity of the jet pump assembly is of paramount importance to safe plant operations. The jet pump ensures reflooding to at least 2/3 core height in the event of a concurrent recirculation pipe break, and for some BWRs, the jet pump assembly provides a flow path for low-pressure injection.

Potential for Regulatory Action: Research should be undertaken to determine the cause of jet pump fatigue cracking and develop solutions before regulatory action or scrutiny is necessary.

RESULTS IMPLEMENTATION

Improved jet pump inspection guidance (BWRVIP-41R3 and NRC approved BWRVIP-41R3-A) and repair guidance (BWRVIP-51R1 and NRC approved BWRVIP-51R1-A) will be developed applying lessons learned during the test program as well as insights from the jet pump degradation and operational history review. Nuclear plant owners will implement the revised jet pump inspection and repair guidance in accordance with NEI-08 implementation guidelines.

Results of BWRVIP testing to investigate jet pump phenomena will allow utilities to assess their relative susceptibility to jet pump degradation based on jet pump design and plant operating conditions. The results will also provide the basis for defining a “demonstration test protocol” to assess the effectiveness of proposed flow-induced vibration mitigation solutions.

Demonstration test results will be provided to BWRVIP utilities by each participating vendor and can be used to inform decisions on potential implementation of one or more jet pump mitigation solutions.
PROJECT PLAN

The jet pump degradation management research program includes compilation of plant data on jet pump degradation, plant operation and repair histories to understand relationships between plant operation, configuration and degradation, sub-scale phenomenological testing to study the slip joint leakage flow instability phenomenon, and full-scale testing of prototypical jet pump assemblies to assess the effectiveness of vendor-proposed flow-induced vibration mitigation solutions. In addition, lessons learned from testing, and insights from the jet pump degradation and operational history review, will be factored into revisions to jet pump inspection and repair guidelines.

Accomplishments to date include compilation of jet pump degradation and operational history information, sub-scale testing at 1/5th and 1/2 scale to better understand the slip joint instability phenomena, testing using a full scale mock-up of a typical slip joint configuration to assess the relationship between slip joint flow and differential pressure, and fabrication of a full-scale test facility that includes a BWR/4 jet pump assembly and a system to provide slip joint leakage flow up to 180 F. Tests completed to date have reproduced the SJLF instability phenomenon and highlighted the need for on-line measurement of the slip joint gap and well as remote control of the alignment between the mixer and diffuser to provide repeatable test results.

In addition, two vendor proprietary conceptual designs for improved lateral support of the jet pump mixer/diffuser have been developed and are documented in BWRVIP-207 and 210. These designs hold promise to significantly reduce the potential for flow-induced vibration (FIV) damage to jet pump components.

Going forward, the full-scale test facility will undergo modifications to allow full flow testing of both BWR/4 and BWR/5 full scale jet pump assemblies up to 600 psia and 320 F. Under these conditions, the facility will be capable of reproducing prototypical turbulent pressure loading, slip joint instability excitation and pressure pulsations from recirculation pump vane passing. The facility will be used to define operating conditions and jet pump configurations that result in "worst case" flow-induced vibration loading. Based on the results, a worst case "demonstration test protocol" will be developed for use in evaluating vendor-developed flow-induced vibration mitigation solutions. At the completion of the EPRI research, the test facility will be made available to participating vendors at their cost to assess the effectiveness of their solutions in mitigating flow-induced vibration loading.

RISKS

The program is thought to have a sound technical basis; however, there is potential risk in the following areas:

- Testing will be conducted at non-prototypical temperature (320 vs 532 F) and pressure (600 vs 1000 psia) conditions. The difference in pressure is not considered significant. Temperature, however, affects the kinematic viscosity which influences the onset of the slip joint instability phenomenon. Since the kinematic viscosity at 320 F is very close to that at 532 F, this effect is considered small and manageable.
- Only two of the 12 jet pump designs in the fleet are being tested (Typical BWR 4 and BWR 5 251 designs). These designs are typical of the designs currently experiencing the most significant degradation. Accordingly, the results are expected to be representative of the fleet.
- To obtain repeatable results, extreme care must be taken to ensure consistent slip joint concentricity between tests. The test facility will include a specialized system for remote measurement and control of slip joint concentricity.
- The effectiveness of FIV mitigation solutions to be tested is not assured.
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Utilities

- Results from Re-baseline Inspections Required by BWRVIP Interim Letter on Riser Cracking
- Implement
- Implement
- Implement

Materials Degradation/Aging

- Low Flow & Pressure Testing
- Full Flow Testing
- Testing of FIV Mitigation Solutions
- Update BWRVIP-41 (I&ES Guidance)
- NRC Review of BWRVIP-41

BWR Vessel and Internals Project

- Update BWRVIP-51 (RDC)
- Publish Approved BWRVIP-51-A

Government

- NRC Review of BWRVIP-51

Vendor

- Develop FIV Mitigation Solutions

Legend

- Key Milestone
- Funded Work
- Unfunded Work