

Experience with Flow-Induced Vibration

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Design

- **Westinghouse has designed and manufactured steam generators (SGs) for 40+ years**
- **Potential for flow-induced vibration (FIV) is routinely analyzed in every SG design**
 - **Tubes**
 - **Moisture Separators/Dryers**

Design

- **Input parameters and methodologies used in FIV analysis are documented in the technical literature**
 - **Extensive testing performed to support analytical methodology**

Design

- **Improvements in analytical methods have been made as operating experience and test data have evolved**
 - **Replacement steam generator (RSG) U-bend assemblies have incorporated design enhancements**

Manufacturing

- **Field modifications have been effective in resolving original SG FIV issues**
 - **Complete anti-vibration bar (AVB) assembly replacement**
 - **Pre-heater modifications**

Manufacturing

- **Westinghouse manufacturing processes have improved for RSGs and new SGs**
- **Advanced AVB design since 1990s**
 - **Tighter dimensional controls on components**
 - **Improved assembly, oversight and documentation**

Operating Experience

- **Original SGs**

- **Good performance with few issues observed**

- **A limited amount of AVB wear has been observed in different models**
 - **Some short-term rapid wear in early life due to manufacturing issues has been observed**
 - **Over the long term, with a few exceptions, AVB wear has not challenged pressure boundary integrity**

Operating Experience

- **AVB replacements in 19 original SGs, implemented 1985 – 1993**
 - **Effectively minimized AVB wear in Model 51 and one Model F plant by incorporating an expandable design**
 - **Other Westinghouse model SGs did not have wear issues**

Operating Experience

- **Model D3 - FIV issues resulted in tube leak in a Westinghouse pre-heater SG design**
 - **Field modifications to divert flow in pre-heater**
- **Model D4/D5 – Pre-heater wear not as severe as Model D3 (no tube leaks)**
 - **Tube expansion**
 - **Split feedwater flow**

Operating Experience

- **Replacement SGs**
 - **No significant operational issues have been observed**
 - **A fraction of 1% of tubes have experienced AVB wear**
 - **Many Westinghouse RSGs have no AVB wear indications after one or more cycles of operation**

Chronology of Significant FIV Issues

- **AVB Wear Resulted in Tube Leak (1983, Model 33)**
 - **Related to manufacturing issue**
- **Pre-heater Wear (1983, Model D3)**
 - **Caused by turbulence and out-of-plane fluidelastic instability**
 - **Resolved by flow control modification and improved tube support**

Chronology of Significant FIV Issues

- **Tube Rupture due to High Cycle Fatigue (1987, Model 51)**
 - **Caused by denting at top tube support and variation in AVB insertion depth**
 - **Addressed by analysis, the installation of sentinel plugs and stabilizers in a few tubes at some plants in response to NRC Bulletin 88-02**

Chronology of Significant FIV Issues

- **Rapid AVB Wear (1992, Model F)**
 - **Related to manufacturing issue in one SG**
 - **Resolved by AVB replacement (improved gap control)**

Recent SONGS RSG Experience

- **Westinghouse performed an evaluation for SONGS Unit 2 addressing tube wear at AVBs, tube-to-tube wear (TTW) and the potential for in-plane instability in the U-bend**
 - **Westinghouse concludes that TTW observed in two tubes in Unit 2 results from proximity of the tubes and out-of-plane vibration and/or in-plane turbulence and not from in-plane instability**

Recent SONGS RSG Experience

- **Eddy current data shows:**
 - **No extension of wear scars beyond the width of the AVB, not only in these tubes, but other tubes in Unit 2 as well**
 - **Vibration due to in-plane instability will cause extension of the wear scars beyond the width of the AVB, as observed in Unit 3**
- **The two Unit 2 tubes with TTW have no indications of top tube support plate wear as found with tubes with in-plane instability in Unit 3**

Recent SONGS RSG Experience

- Westinghouse evaluation was documented in an operational assessment for the three degradation mechanisms**

Summary

- **Westinghouse has observed issues related to FIV in the past in original SGs**
- **As a result of our experience with tube wear and fatigue over the past two decades, we have incorporated enhanced design, manufacturing, and oversight into our RSGs and recent new SGs**

Summary

- **Westinghouse strives for zero wear through our design and manufacturing; as a result, minimum wear has been observed**
- **Tube wear in original SGs in service is managed in accordance with NEI 97-06 SG performance criteria**
- **SGs satisfy performance criteria and are safe to operate**