Fatigue Risk Evaluation of a Pressure Vessel Plug Subject to Flow Induced Vibration

Case study

The steam generator channel head on a pressurised water reactor forms part of the reactor coolant pressure boundary and is of high nuclear safety duty. Failure of the channel head is considered intolerable. There is the potential for vibration of the drain plug due to coolant flow to result in fatigue induced failure of the channel head drain penetration weld. EASL undertook random vibration analyses and a fatigue assessment for a submerged drain plug in a steam generator channel head with the aim of demonstrating that the client's plant is not at risk of failure due to vibration.

Understanding the problem

The response from a forced vibration normally requires definitive forcing functions as input. In fluid flow-induced vibration, the forcing functions applied to a structure are not easily obtained. Computational fluid dynamics (CFD) analysis could be performed from which the output could be used as the input to the subsequent structural analysis. However, EASL recognised that there are large uncertainties with the CFD approach and also the associated cost would be high.

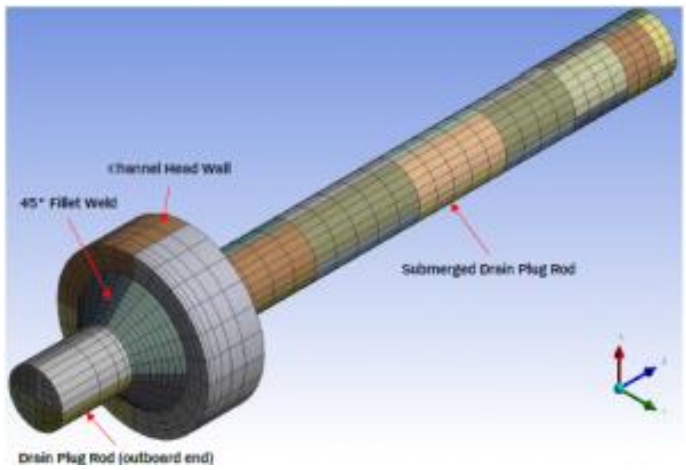

Figure 1 3D finite element model representing the welded drain plug assembly

EASL's solution

It was judged that an approach using energy based evaluation of fluid flow-induced excitation would be more cost effective and appropriate. Therefore, an energy-based random vibration analysis approach was employed in this work. Coupled with the energy based input, random vibration analysis could then be employed for the derivation of vibration stresses which could then be used in subsequent fatigue assessment. Hence, a finite element (FE) model of the drain plug submerged in water coolant was developed.

Modal analyses using this model confirmed what was expected in that the natural frequency of the submerged drain plug is significantly reduced by the large hydrodynamic added mass from the surrounding fluid.

The subsequent fatigue evaluation at the drain plug root due to fluid flow-induced vibration was undertaken using an appropriate ASME III fatigue curve. This concluded that the fatigue life usage due to the vibration of the drain plug is negligible.

Discussion

A key part of this study was to capture fluid-structure interaction between the drain plug and the surrounding coolant water in the penetration annulus. Modern FE structural analysis software provides co-simulation techniques which allow interaction between different physical analysis programs.

Our study presents an energy-based approach for the evaluation of fatigue failure risk due to fluid flow-induced vibration. Recognising the random nature in fluid flow-induced vibration, the energy loss in the fluid flow was conservatively taken as the source for excitation. An FE model of a steam generator channel head drain plug has been generated and subject to a random vibration analysis procedure in ANSYS to derive statistical stress amplitudes. Comparing these stress amplitudes with ASME III fatigue endurance, it has been demonstrated that the risk of fatigue failure due to fluid flow-induced vibration of the drain plug welded to a steam generator channel head is acceptable until end of operational life.

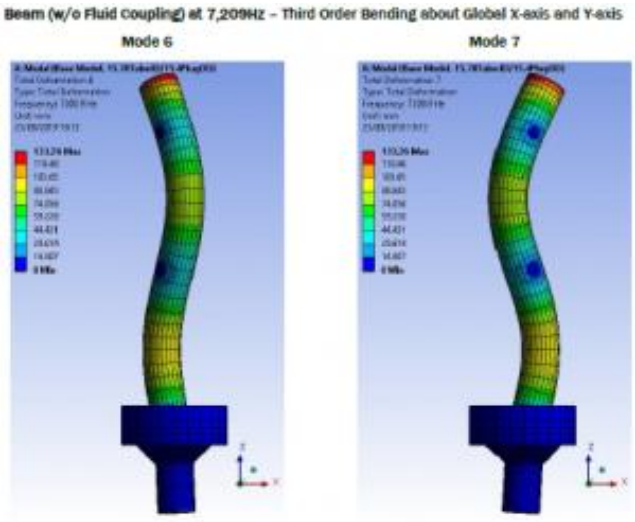

Figure 2 Modal excitation of the welded drain plug assembly

Other applications

EASL have extensive capability in advanced FE and CFD techniques and also in how to utilise the output in assessments – in this case a fatigue assessment. EASL always work with clients to identify cost effective solutions to operational challenges.

If you would like to discuss how EASL can help your business please get in touch.

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