

LES Analysis of a 1/5-Scale i-SMR CVAP Model for Pressure PSD Generation

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1. Introduction

A Comprehensive Vibration Assessment Program (CVAP) is required to evaluate the integrity of reactor internal structures in the innovative Small Modular Reactor (i-SMR) [1]. The CVAP test evaluates flow-induced pressure fluctuations and the resulting vibration responses of the internal structures. Accordingly, the CVAP requires a 1/5-scale reactor model that reproduces the prototype flow characteristics and a corresponding numerical model of the test facility. Previous studies examined the pressure similarity of a scaled i-SMR steam generator model [2] and evaluated the flow rate and pressure-drop characteristics of a reduced reactor model using steady-state CFD [3]. However, the rotation of the reactor coolant pump (RCP) and unsteady turbulent flow need to be considered to obtain pressure time histories for generating power spectral density (PSD) data for subsequent flow-induced load generation.

In this study, a large eddy simulation (LES)-based CFD model of the 1/5-scale i-SMR reactor was developed. Grid and turbulence-model sensitivity studies were performed to select the mesh and initial flow field for the LES analysis. The RCP rotation was then included in the LES analysis, and pressure time histories were obtained at CFD monitoring points corresponding to the pressure sensor locations in the test facility for subsequent PSD generation.

2. Methods

A three-dimensional, one-quarter symmetric computational domain was constructed to include the main internal flow paths of the reactor, as shown in Fig. 1. The CFD analysis was performed using STAR-CCM+ (Siemens, USA). The continuity and momentum equations were solved for incompressible, single-phase water.

The boundary conditions were based on the test conditions derived from the i-SMR design specifications. The inlet boundary was located at the RCP inlet and specified as a mass-flow inlet with the 100% design flow condition. The outlet boundary was located on the opposite side and specified as a pressure outlet with a gauge static pressure of 0 Pa. Symmetry

conditions were applied to the symmetry planes, while no-slip conditions were applied to the remaining walls.

Four grid models and three RANS turbulence models were compared to select the mesh and initial flow field. A mesh of approximately 67 million cells was selected, and the steady-state solution obtained using the SST $k-\omega$ model was used as the initial condition for the LES analysis. The Wall-Adapting Local-Eddy Viscosity (WALE) model was used as the subgrid-scale model. The RCP impeller rotation was directly modeled using rigid body motion (RBM), and the time step was set to 5.0×10^{-4} s. Pressure time histories were recorded at CFD monitoring points corresponding to the pressure sensor locations in the test facility and were used to generate pressure PSD data for subsequent flow-induced load generation.

3. Results

Fig. 2 shows the pressure and velocity distributions at a selected time instant during the LES. Pressure decreased along the main flow path from the RCP discharge through the steam generator, downcomer, and core to the RCP inlet. Flow accelerated in narrow passages, resulting in nonuniform velocity distributions around the internal structures.

Pressure was monitored in the CFD model at locations corresponding to the pressure sensors in the test facility. Fig. 3 presents examples of the pressure time histories obtained at selected monitoring points. The mean pressure level and fluctuation amplitude varied with location. As a preliminary step before

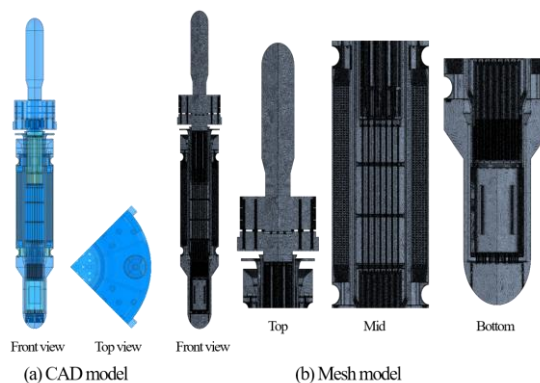


Fig. 1. Computational domain and mesh of the 1/5-scale i-SMR reactor model.

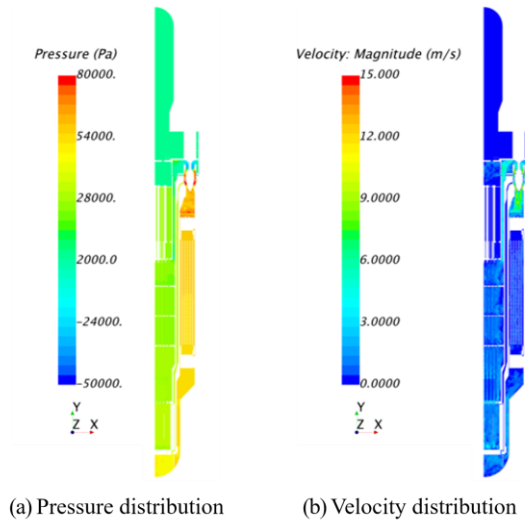


Fig. 2. Representative pressure and velocity distributions obtained from the LES analysis.

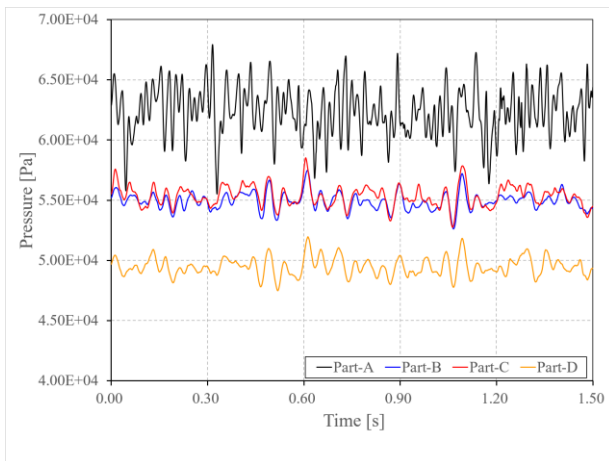


Fig. 3. Pressure time histories at selected monitoring points corresponding to pressure sensors in the test facility.

quantitative comparison with the experimental data, this study presents pressure time histories obtained from the LES analysis. These data were used to generate pressure PSDs for subsequent flow-induced load generation.

4. Conclusions

In this study, an LES-based CFD model of the 1/5-scale i-SMR reactor was developed. A mesh of approximately 67 million cells was selected through grid and turbulence-model sensitivity studies, and the steady-state SST $k-\omega$ solution was used as the initial flow field for the LES analysis. The RCP impeller rotation was directly modeled using RBM, and pressure time histories were obtained at locations corresponding to the pressure sensors in the test facility and were used to generate pressure PSD data.

The developed model can provide pressure time histories for generating pressure PSDs, which can be used to generate flow-induced loads for subsequent structural vibration evaluation in the CVAP test. Future

work will validate the numerical model through comparison with experimental results and perform a sensitivity analysis of the unsteady simulation conditions.

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