Transactions of the Korean Nuclear Society Autumn Meeting 2021

Numerical Calculation of Forcing Functions of Turbulence Induced Vibration by the RCP of APR1400

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Introduction

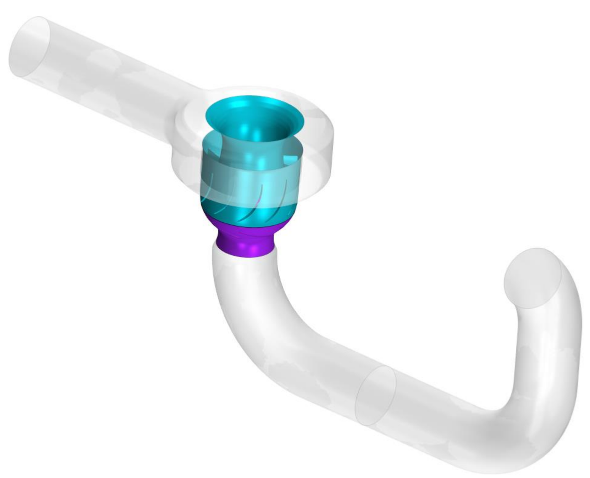

Fig. 1. Analysis domain of Reactor coolant pump

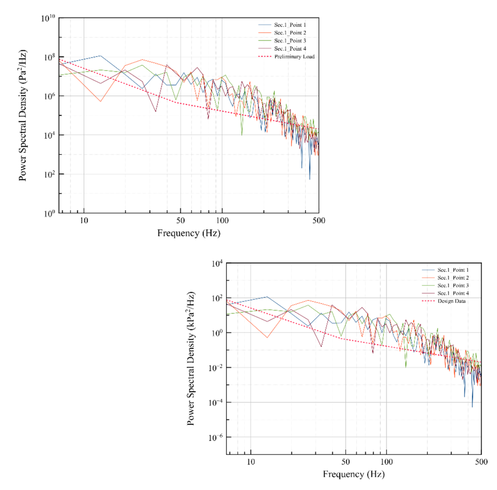

Fig. 2. Power spectral density

- Pressure pulsations induced by rotation of the Reactor Coolant Pump (RCP) impeller of APR1400 is one of the main causes for vibration-induced load.
- These pressure disturbance components, that is, periodic pressure fluctuations propagate through discharge leg of the RCP, leading to structural damage from fatigue.
- The purpose of this study is to obtain the pressure fluctuations in the RCP discharge leg, which are transformed into Power Spectral Density (PSD) to be utilized as forcing function and compared with the design data to validate the numerical analysis methodology.

Numerical analysis

❖Numerical Analysis Model

	RANS	LES
Turbulence Model	Realizable k-ε Two-Layer	WALE
Time Domain	Steady	Transient (Unsteady)
Impeller Motion	Moving Reference Frame	Rigid Body Motion

Numerical analysis model

- In steady RANS, MRF method and Realizable k-ε two-layer model were used.
  - MRF : approximates the effect of a rotating impeller on the surrounding flow field without moving grids.
  - Realizable k-ε two-layer model : turbulence model.
- In unsteady LES, rigid body motion and Wall-Adapting Local-Eddy viscosity (WALE) were used.
  - Rigid body motion : involves mesh motion.
  - WALE : automatically gives accurate scaling at walls without requiring any form of wall-damping.

❖Grid and Boundary conditions

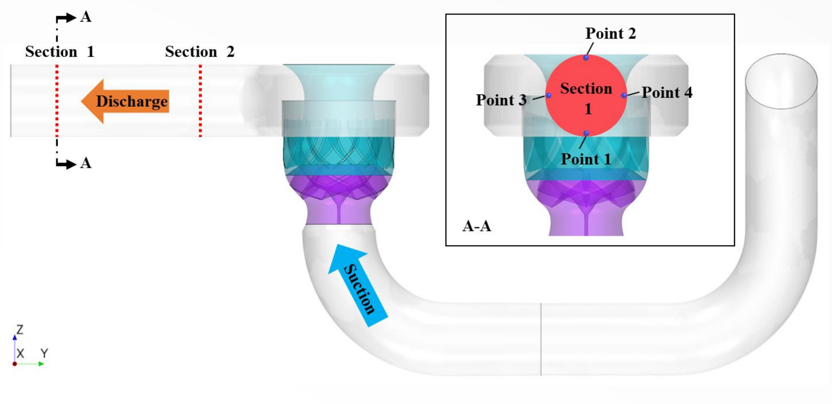

Fig. 3. Geometry of the RCP fluid domain

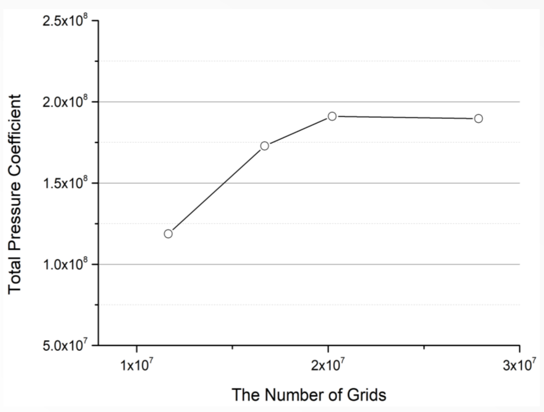

Fig. 4. Grid dependency test

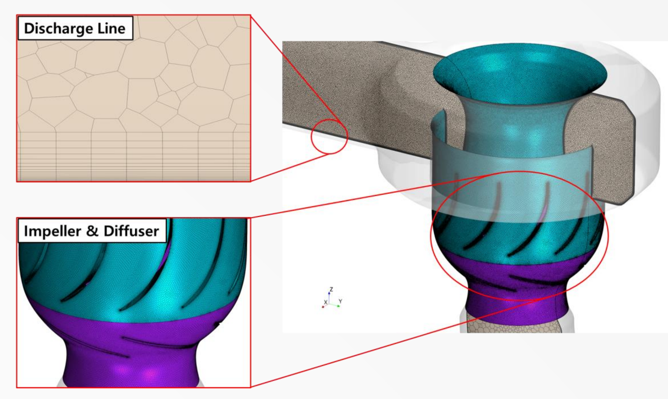

Fig. 5. Grid systems

- The geometry model of numerical simulation is the RCP of APR1400, which is a vertical single-stage centrifugal pump. Reactor coolant flows vertically from below into the pump with 6-blade impellers and 11-blade guide vanes.
- Grid dependency test was performed to assure grid independence using total pressure coefficient, concluding grids over 20 million cells are reliable.
- Polyhedral grids were used for grid systems consisting of 24 million cells, determined by grid dependency test.
- The operating pressure, temperature and flow rate are 15.24 MPa, 290.56 ℃ and 7.67 m^3/s, respectively.
- The LES calculation was initialized with the steady RANS solution with the time step of 1.4 E-4 s, which is small enough to get time resolution for the grid movement and dynamic analysis at 1190 rpm.

Results & Discussion

❖Pressure distribution

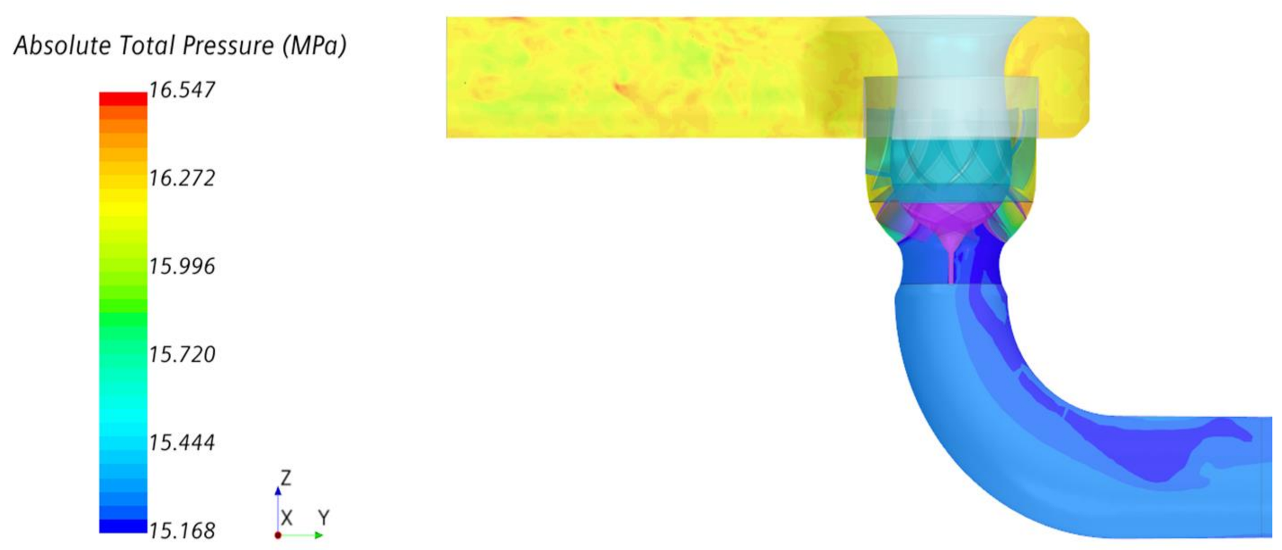

Fig. 6. Pressure distribution (LES) on the impeller center section plane

- The absolute total pressure distribution was obtained for impeller center section plane.
- The pressure is increased through the impeller since the kinetic energy of the rotating impeller is added to the flow and transformed into the pressure energy by the diffuser.

❖Power Spectral Density

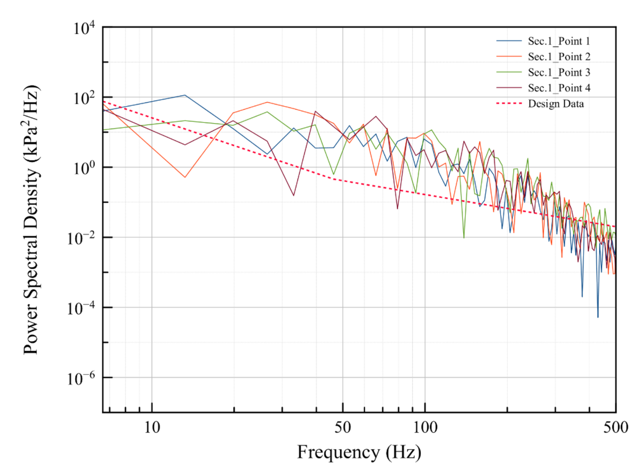

Fig. 7. PSD for pressure fluctuation on the RCP discharge leg in Section 1

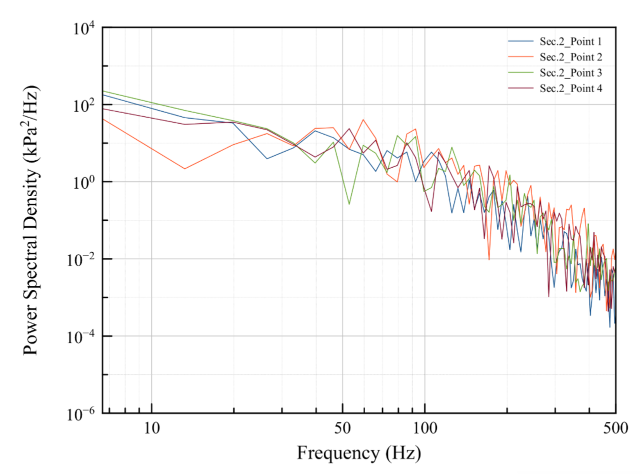

Fig. 8. PSD for pressure fluctuation on the RCP discharge leg in Section 2

- Figs 7 and 8 show the PSD for pressure fluctuation on sections 1 and 2 as depicted in Fig. 3.
- In Fig. 7, the PSD design data at Core Support Barrel (CSB) of APR1400, to which the measuring points in section 1 are nearest, were compared with the numerical result of the PSD in section 1. The PSDs from the numerical result were calculated slightly higher than the design data in the low frequency region below 200 Hz, but showed a good agreement with similar trends.
- The PSDs in section 1 and 2 were also following the similar trend but the peak value of section 2 were 225E2 kPa^2/Hz, twice higher than that of section 1, 114E2 kPa^2/Hz.

Conclusions

A numerical simulation of the unsteady flow in the RCP of APR1400 was carried out. The pressure distribution was obtained through the steady RANS calculation. The pressure fluctuations were subsequently obtained by utilizing the steady results as initial condition to the LES calculation.

- The results showed that the PSD, that is, forcing functions were similar in Figs. 7 and 8 but with different peaks.
- The result was compared with the design data of APR1400 and showed a good agreement.
- Although the peaking value at RCP blade passing frequency has not been obtained, the results presented in this study may give guidelines to the numerical analysis of RCP induced pressure fluctuations, associated design data generation and investigation of forcing functions for further optimal design of the RCP.

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