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Flow characteristics in a volute-type centrifugal pump using large eddy simulation

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ABSTRACT

The flow characteristics in a volute-type centrifugal pump operating at design (Q_d = 35 m^3/h) and off-design (Q_{off} = 20 m^3/h) conditions are investigated using large eddy simulation. Numerical results indicate that separation bubbles are generated on both the pressure and suction sides of impeller blades. At the off-design condition, the blade pressure side contains a larger recirculation zone with highly unsteady characteristics due to impeller-volute interactions. The vortices shed from a blade trailing edge due to its rotation strongly interact with those from the following blade and leakage through radial gaps at the off-design condition, generating stronger vortices in a wider region inside the volute, whereas this mutual interaction is weak at the design condition. Flow separation also occurs around the volute tongue at both operating conditions. At the off-design condition, a part of high-pressure fluid discharged from the volute does not follow the main stream to the outlet duct but re-enters into the volute area near the volute tongue. This pressurized fluid forms a high adverse pressure gradient on the blade pressure side, resulting in strong unsteady separation there. Also, a high pressure gradient in the axial direction at the radial gaps is formed especially near the volute tongue, creating the leakage into the cavities. Inside the volute, azimuthal vortices exist and grow along the volute passage. A secondary motion induced by these vortices also significantly affects the leakage to the cavities. All of these flow losses contain unsteady features that are strongly influenced by impeller-volute interactions, especially at the off-design condition.

1. Introduction

A centrifugal pump, which is one of the most commonly used turbomachines, is widely utilized in residential buildings as well as in industries. In centrifugal pumps, complex three-dimensional flow phenomena involving turbulence, secondary flows and unsteadiness occur (Brennen, 1994). To meet various ranges of pressure rise and flow rates required, many centrifugal pumps are operated at off-design conditions as well as at the design condition. At off-design conditions, the flow characteristics inside centrifugal pumps become more complex than those at the design condition. Commonly used steady Reynolds-averaged Navier-Stokes (RANS) turbulence models often inaccurately predict the flow inside centrifugal pumps at off-design conditions (Byskov et al., 2003). For this reason, a large eddy simulation (LES) technique is a promising alternative to predict such complex flow phenomena inside centrifugal pumps.

Kato et al. (2003) conducted LES to predict the flow in a mixed-flow pump at off-design conditions, where the standard Smagorinsky model together with the van Driest damping function near the wall was used as a subgrid-scale model. The results from LES were compared with those measured by a laser Doppler velocimetry (LDV) and good agreements were obtained. Byskov et al. (2003) studied the flow in a shrouded six-bladed centrifugal pump impeller at design and off-design conditions using the localized dynamic Smagorinsky model (Piomelli and Liu, 1995). They showed that, at an off-design condition, LES predicts complex flow phenomena, such as steady nonrotating stalls and flow asymmetry between impeller passages, better than RANS. Although most of previous LESs of flows in centrifugal pumps used the standard Smagorinsky model or simulated flow only in rotating parts, LESs using more advanced subgrid-scale models such as a filtered structured function model (Posa et al., 2011) or a wall-adapting local eddy-viscosity model (Posa et al., 2015, 2016) were also performed to study the flow structures in a mixed-flow pump including all rotating and stationary parts. They showed that LES accurately predicts unsteady flow features, such as separated flow near the blade surfaces, backward flow near the shroud surface and rotor-stator interaction, at design and off-design conditions. A detached eddy simulation (DES) was also conducted to study the flow in a radial diffuser pump at low

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