Numerical 3D simulation of the cavitating flow in a low specific speed centrifugal pump and assessment of the influence of surface roughness on head prediction

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Long Abstract

Introduction

Numerical simulation of cavitating flows in hydraulic machinery gets increasingly important in the design process and yields an insight in the complex flow in addition to measurements. However, due to the complexity of the physics of cavitation, available cavitation models include simplifications of the flow physics and do not seem to be predictive. Therefore, a thorough validation on experimental data is necessary. Commonly, for the simulation of cavitation in centrifugal pumps, incompressible, implicit flow solvers are used in combination with mass transfer cavitation models based on the Rayleigh-Plesset or the simpler Rayleigh equation. This model class has been applied for the simulation of cavitating flow in centrifugal pumps of high or intermediate specific speed in order to evaluate the characteristics of head drop and Net Positive Suction Head (NPSH) with reasonable accuracy compared to measurements (e.g. [1]). However, the accuracy of the prediction of suction performance is case-dependent according to Nohmi [2], in particular for low specific speed pumps. This observation is confirmed by other authors: for example, for the evaluation of the NPSH characteristics of a centrifugal pump with low specific speed significant deviations to the measured data have been observed by Limbach et al. [3]. The results of the pump head are already overestimated for single-phase flow conditions, which has also been observed by Juckelandt et al. [4], who attributed the neglect of the surface roughness to be one reason for the mismatch between simulation and measurement data. Varley [5], Gülich [6] and Tamm et al. [7] varied the roughness of various impeller components of different centrifugal pumps and registered a slight increase of the head with increasing roughness in their experiments. Furthermore, Gülich [6] and Tamm et al. [7] identified the roughness of the volute to have more significant influence on the head (head decreases with roughened volute).

The present paper focusses on the improvement of the numerical model in order to reliably predict the head drop due to cavitation in a low specific speed centrifugal pump. Therefore, the influence of several geometry and model simplifications on the pump head in single-phase and cavitating flow conditions and particularly the effect of inclusion of roughness models is analysed.

Method

In the study a numerical analysis of the head for single-phase and cavitating flow conditions of a low specific speed centrifugal pump (n_q = 12 1/min) is performed using a commercial three-dimensional flow solver (ANSYS CFX 15) in combination with a mass transfer cavitation model by Zwart et al. [8]. Besides the transient Reynolds-averaged Navier Stokes equations, an additional transport equation for the void fraction is solved, which contains a source/sink term to account for vaporization and condensation, based on simplified bubble dynamics (Rayleigh equation). The basic geometry model of the pump contains the impeller, the volute casing, side chambers and the suction pipe as well as the pressure pipe. Single-phase flow simulations are performed for six flow rates (3x partload, nominal load and 2x overload conditions). A mesh sensibility analysis is performed to ensure the numerical quality. In extension to our previous study [3] we analyse the influence of geometry simplifications on the head for single-phase flow conditions, i.e. balance holes for the reduction of axial thrust, radial clearance, ribs in the suction pipe and the radii between the blades and hub/shroud. In addition, since the measured pump has a considerable surface roughness, a roughness model based on a modified wall function is investigated for single-phase and cavitating flow conditions. Simulation results are compared to head and suction head data from the pump manufacturer and in-house measurements.

Results

For hydraulically smooth walls the head is significantly overestimated by CFD in overload. The influence of geometry simplifications and slight variations of radial clearance is minor, whereas an improvement of the prediction is observed when the volute roughness is taken into account. The neglect of the roughness is one major origin of result discrepancy between experiment and simulation in low specific speed pumps.

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