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Numerical Analysis of the RCP Performance with the Surface Roughness of the Impeller and Diffuser in the Full-Scale and Down-Scale Models

Soon-Chan Hwang [a], Hyun-Gi Yoon [b], Jong-Ho Park [c*]
[a] *Energy Plant Research Division, KIMM, Daejeon*
[b] *Division for Research Reactor Core and System Design, KAERI, Daejeon*
[c] *Mechanical Eng. Dept., Chungnam National University, Daejeon*
Corresponding author: jhpark@cnu.ac.kr

1. Introduction

RCP (Reactor Coolant Pump) is the coolant circulation pump in the nuclear power plant. In the general fluid system, its flow rate is controlled by using the control valve. Therefore, the circulation pump is selected with a sufficient operation margin. But, in the nuclear system, primary cooling system is operated without a control valve to ensure the safety of the reactor. So, exact fluid system analyses to calculate the pressure drop and pump design are required in the primary cooling system. In the system design stage, system designer calculated the rated coolant flow rate based on the heat balance, required head, $NPSH_A$ (Available Net Positive Suction Head) and other requirements. And then, the appropriated pump is designed and tested by the equipment designer.

In the resent years, CFD (Computational Fluid Dynamic) method is widely used in the detailed design and analysis of the pump. In the present study, hydraulic performance analysis of the RCP is carried out numerically with the various surface roughnesses of the impeller and diffuser in the full-scale and down-scale models

2. Numerical Analysis

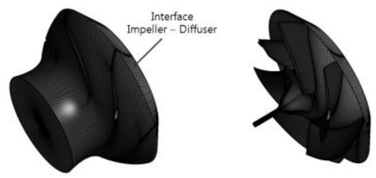
RCP is designed as a mixed type pump with the flow coefficient of 0.631 and the head coefficient of 0.981. RCP consists of impeller, diffuser and casing and its geometry, configuration and mesh strategy for numerical calculation are represented in Fig. 1. And, the non-dimensional specific speed and specific diameter are respectively 1.77 and 2.17. These values are in the range of the mixed pump according to the Cordier line.

2.1 Reynolds number and Calculation models

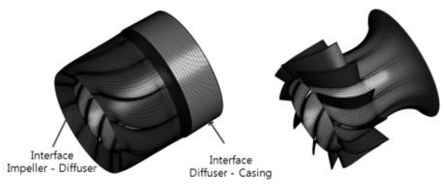
Pressure drop in the fluid system equipments is generally calculated from the resistance coefficient and velocity as described in Equation (1).

$$h_l = k\frac{V^2}{2g} \tag{1}$$

At here, resistance coefficient is estimated based on the geometry of equipment, Reynolds number and relative roughness. Generally, friction factor from the Moody chart is used to predict the resistance coefficient. This chart shows the relationship between the Reynolds number and the surface roughness. The difference between the friction factors with the grade of the relative roughness is getting wider and wider as increased Reynolds number. In the present research, three cases of surface roughness are assumed as explained in Table. 1. And, full-scale and down-scale of 28% model are also studied.



Impeller



Diffuser

Casing and CFD model

Fig. 1. Geometry and Mesh strategy for numerical simulation

Table 1. Simulation cases and sand grain roughness

Case	Scale	Reynolds number	Sand grain roughness
1	Full	1.1E+8	0mm (Smooth)
2			0.003mm
3			0.046mm
4	28% Down	1.5E+6	0mm (Smooth)
5			0.046mm

2.2 Numerical Simulations

Inlet and outlet boundary conditions are depicted in Fig. 2. Almost 2 million number of hexahedra elements are used in this simulation. Calculation meshes of the impeller, diffuser, pipes and casing are generated by using the CFX turboGrid and ICEM CFD. Commercial code, CFX 13.0, is used for numerical simulation. SST model based on k-w is applied as a turbulent model. And heat transfer model is not considered. Performance calculation is conducted at only design flow rate.

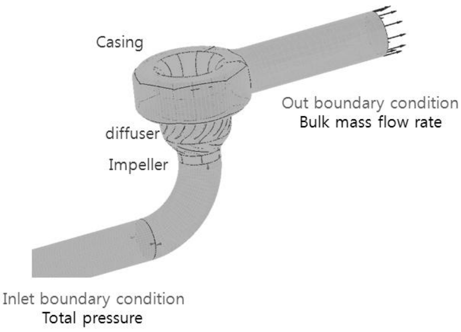


Fig. 2. Boundary conditions

2.4 Results

Calculation results are summarized at Table 2. 2D and 3D stream line are shown in Fig. 3.

Table 2. Calculation results

Case	Total head raise	Efficiency
1	127.2m	86.4%
2	124.9m	85.9%
3	107.6m	80.0%
4	11.7m	79.6%
5	10.6m	75.8%

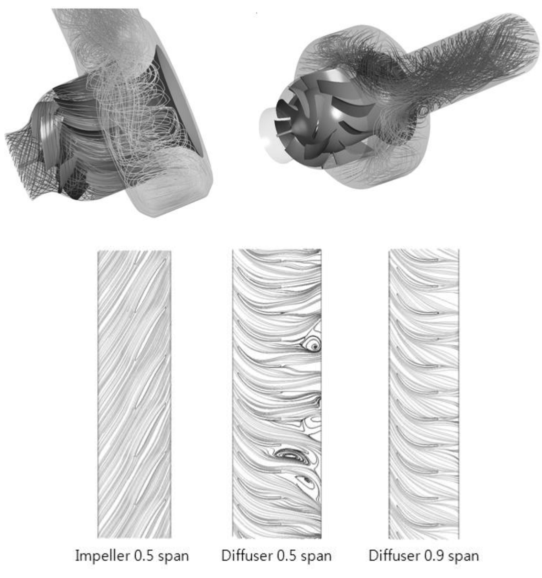


Fig. 3. Streamline in the Pump

3. Conclusions

RCP performance is calculated at the design point to investigate the effect the surface roughness and high Reynolds number. Pump total head and efficiency are goes down as increased surface roughness and Reynolds number.

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