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Preliminary Design of the Primary Coolant Pump in the Research Reactor

Hyun-Gi Yoon [*], Kyoung-Woo Seo, Dae-Young Chi and Juhyeon Yoon
Fluid System Design Division, Advanced Reactor Development Institute, KAERI, Daejeon
[*]Corresponding author: hyungi@kaeri.re.kr

1. Introduction

Primary coolant pump (PCP) circulates the coolant from the reactor core to the heat exchanger in the primary cooling system in order to remove the heat generated from the reactor core in the research reactor. Rated flow rate and head for a pump design are calculated based on the thermal design flow rate, measurement uncertainty, error of the system resistance curve, aging effect of the plant and so on.

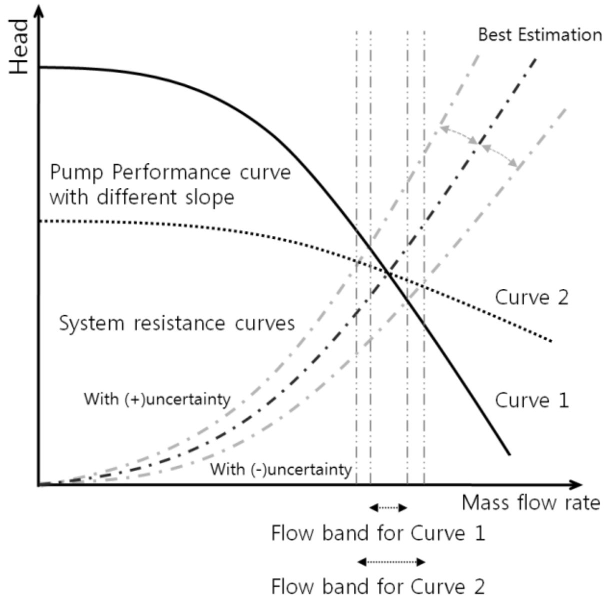

Fig. 1. Flow band with the different pump performance curves and system resistance curves.

2. Design Limits

A steep slope of the pump performance curve near the rated flow rate makes the narrow flow band of the system operation. This flow band is determined by the uncertainty of the system resistance curve and pump performance curve as shown in Fig. 1.

Generally, the higher specific speed of the pump gives the steeper slope of the pump performance curve from the pump design point of view.

In the preliminary design stage of the pump, rated head, flow rate and $NPSH_A$ is already calculated as initial design values in the system design stage. Then, pump is conceptually designed by using these design variables. Pump $NPSH_R$, type, size, rpm are intensively investigated in order to insure the safety operation. Conceptual design results are given in Table 1.

Table 1. Conceptual design results

Case	n_s[-]	d_s[-]	$NPSH_R$ [m]	Pump Type
Case 1	0.50	5.82	1	Radial
Case 2	0.66	4.48	2	Radial
Case 3	1.00	2.27	3	Radial
Case 4	1.99	2.12	7	Mixed

3. Cavitation

Cavitation is the most important factor to determine the safety operation of pump because cavitation of the pump makes the mechanical damage of the impeller, strong vibration and loud noise. In order to maintain the safety operation of the pump without cavitation at the impeller, the $NPSH_A$ shall be larger than the $NPSH_R$. Operation margin related to cavitation is generally expressed as a ratio of the $NPSH_A$ and $NPSH_R$. This margin is determined by the working fluid, operation environment and pump energy level. Generally, normal cold water has a margin of 130~150%. But, pump used in the nuclear plant requires a margin of 150~250% according the pump energy level.

Fig. 2 and 3 show the pressure loss coefficient, $NPSH_A$ coefficient of the primary cooling system and cavitation coefficient of the Case 3, respectively.

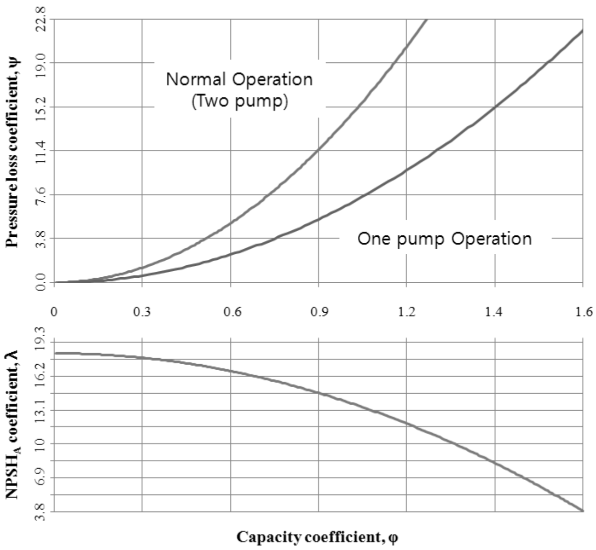

Fig. 2. Pressure loss coefficient curves with operation modes and $NPSH_A$ coefficient curve.

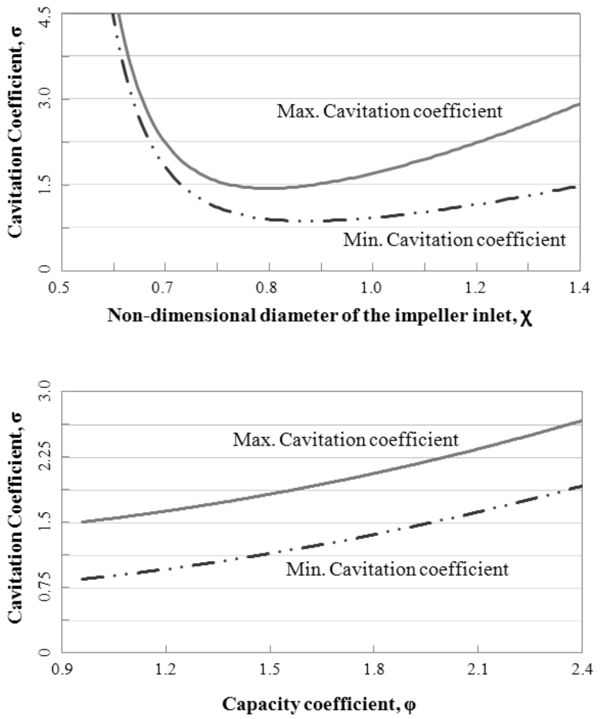

Fig. 3. Cavitation coefficient curves with the non-dimensional diameter of the impeller inlet and capacity coefficient.

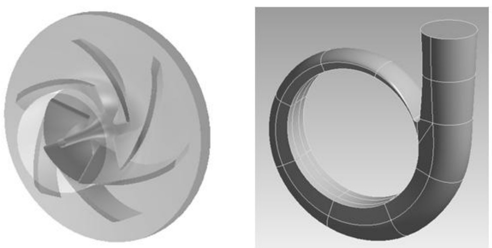

Fig. 4. Impeller and volute geometry of Case 3.

4. Slope of the pump performance curve

Pump performance curve could be estimated from the theoretical head, the hydraulic head loss due to the internal friction of the liquid in the pump and the pressure-head loss caused by the discrepancy of the angle of incidence. The slope of the theoretical head curve of Case 3 is steeper than that of Case 2 based on the following equation 1. Therefore, Case 3 is easier to have a steep slope of the pump performance curve because the rotational speed of Case 3 is faster than that of Case 2.

$$H_{th} = \frac{u_2}{g}\left(u_2 - w_{u2}\right) \tag{1}$$

Nevertheless, the final pump performance curve is obtained by the actual test. Recently, pump performance curve could be predicted by the CFD method. And, CFD results are almost consist with the actual test results near the design point.

Fig. 4 shows the impeller and volute geometry of the Case 3.

4. Conclusions

Centrifugal pump of Case 3 with a non-dimensional specific speed of 1.00 [-] and specific diameter of 2.27 [-] is chosen as the preliminary design of the primary coolant pump based on following reasons.

- Case 1: Low efficiency and over-size of the pump.
- Case 2: Slope of the pump performance curve declines more gradually compared with that of Case 3.
- Case 4: Pump type of diagonal impeller shape is not considered in this research.

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Nomenclature

d	Diameter of the impeller inlet, [m]
d_1	Designed diameter of the impeller inlet, [m]
d_s	Specific diameter, $D\cdot(g\cdot H)^{0.25}/Q_d^{0.5}$, [-]
g	Acceleration of gravity, 9.81[m/s^2]
n_s	Specific speed, $\omega\cdot Q_d^{0.5}/(g\cdot H)^{0.75}$, [-]
u_1	Peripheral velocity at the impeller inlet, [m/s]
u_2	Peripheral velocity at the impeller outlet, [m/s]
w_{u2}	Peripheral component of the relative velocity at the impeller outlet, [m/s]
D	Diameter of the impeller outlet, [m]
H	Pump Head at the design point, [m]
H_{th}	Pump theoretical head for an infinite number of blades, [m]
NPSH	Net Positive Suction Head, [m]
$NPSH_A$	Available NPSH, [m]
$NPSH_R$	Required NPSH, [m]
Q	Flow rate, [m^3/s]
Q_d	Flow rate at the design point, [m^3/s]
λ	$NPSH_A\cdot g/u_1$, [-]
σ	$NPSH_R\cdot g/u_1$, [-]
φ	Q/Q_d, [-]
ψ	Pressure loss[m]$\cdot g/u_1$, [-]
ω	angular velocity of the impeller, [rad/s]
χ	d/d_1, [-]