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Conceptual Design of the Primary Cooling System Pump in Consideration of the Variable Flow Rate in the Research Reactor

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1. Introduction

Primary Cooling System (PCS) pump circulates the coolant in order to remove the heat generated from the reactor core in the research reactor. Typical PCS consists of two parallel 50% capacity pumps for safety as shown in Fig. 1. When one pump stops abnormally, the other is continuously operating to circulate the coolant. If two PCS pumps stop abnormally, the PCS flow rate is decreased slowly by the pump flywheel in order to remove the decay heat.

Design point of the PCS pump is calculated based on the thermal design flow rate, uncertainty of the instruments and system resistance curve, aging effect of the plant and so on.

Thermal design flow rate is determined from the core thermal-hydraulic design. Thermal design flow rates for a research reactor which can be operating at both $3MW_{th}$ and $6MW_{th}$ are considered in this research. During the $3MW_{th}$ operation, PCS could be operated with the flow rate for the $6MW_{th}$. But, PCS flow rate is reduced by the controller while the research reactor is in operation with the $3MW_{th}$ from the perspective of the plant aging effect and economy.

In this research, a required thermal design flow rate is assumed proportional to the reactor thermal power.

PCS pump type, NPSH margin and coastdown flow rate is designed and calculated in this research.

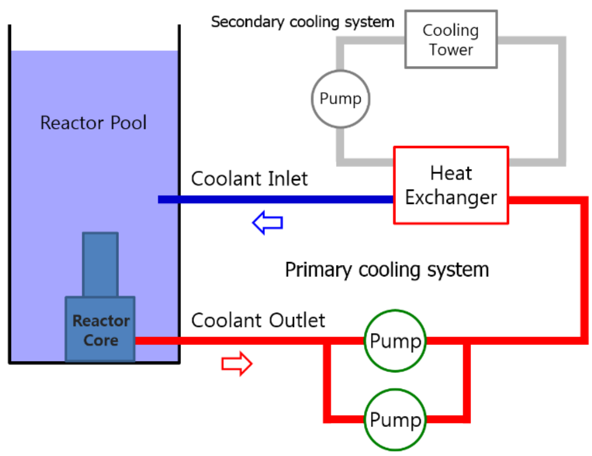

Figure 1. Schematic diagram of the primary cooling system.

2. PCS Pump Type

A centrifugal pump with a non-dimensional specific speed of 0.64 [-] and specific diameter of 4.64 [-] is conceptually considered as the PCS pump. Flow rate is adjusted by the change of the rotating speed of the impeller through the invertor control. Therefore, same pump can be used for the $3MW_{th}$ and $6MW_{th}$ operation. Pump is operated with the affinity laws as following.

Flow rate	$Q \propto \omega$
Head	$H \propto \omega^2$
Power	$P \propto \omega^3$

Pump design point of the flow rate and head is calculated based on the PCS flow band design. 109% of the thermal design flow rate is assumed as the PCS pump design flow rate in consideration of the thermal design flow, measurement uncertainty, plant aging effect and allowable flow band for start-up operation as shown in Fig. 2. Allowable flow band is calculated based on uncertainties of the system pressure drop characteristic, pump performance curve.

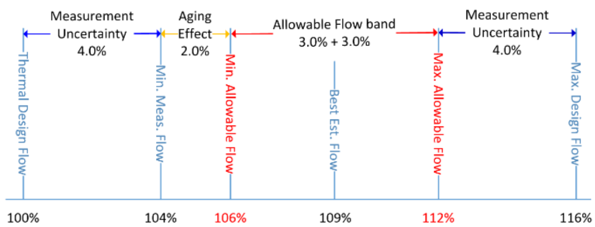

Figure 2. PCS flow band.

3. Cavitation

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

Fig. 3 and 4 show the $NPSH_A$ and $NPSH_R$ coefficient of the PCS pump with the non-dimensional diameter of the pump inlet and capacity coefficient, respectively. These results are calculated from the $6MW_{th}$ operation.

$NPSH_R$ coefficient range from the minimum value to the maximum value is determined from the leading edge design of the impeller. Minimum $NPSH_R$ coefficient is required to secure the sufficient NPSH margin. $NPSH_R$ is verified by the actual pump test.

When PCS pumps operate without cavitation at the flow rate for the $6MW_{th}$ operation, it can operate without cavitation at the $3MW_{th}$ operation. $NPSH_A$ coefficient is increased when the flow are is decreased as shown in Fig. 4. $NPSH_R$ is decreased when the rotating speed of the impeller is slowed down.

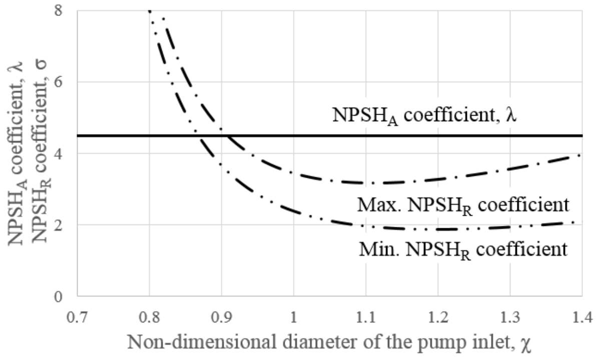

Figure 3. $NPSH_A$ and $NPSH_R$ coefficient with the non-dimensional diameter of the pump inlet

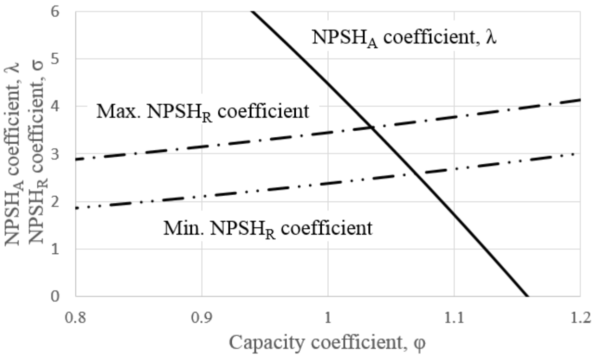

Figure 4. $NPSH_A$ and $NPSH_R$ coefficient with the capacity coefficient

4. Coastdown flow rate

Coastdown flow rate is calculated in consideration of the pump flywheel and linear momentum of the PCS.

In this study, a pump flywheel is designed to supply 80% of the normal core flow rate after 3sec from a pump stop.

Figure 5 shows the coastdown flow rate with the time. Coastdown flow rate satisfy the design requirement. Capacity coefficient at the $3MW_{th}$ operation is higher than that at the $6MW_{th}$ operation because of following relationships.

Flywheel Energy	$E_{flywheel} \propto \omega^2$
Fluid Kinetic Energy	$E_{fluid} \propto \omega^2$
Pump Power	$P \propto \omega^3$

Coastdown flow rate from the fluid kinetic energy is usually ignored for the conservative design.

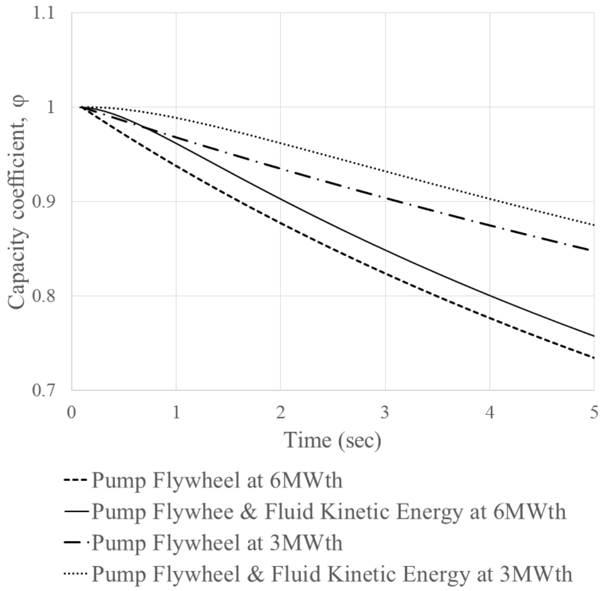

Figure 5. Coastdown flow rate with time

4. Conclusions

A centrifugal pump with a non-dimensional specific speed of 0.64 [-] and specific diameter of 4.64 [-] is conceptually designed in consideration of the NPSH margin and required coastdown flow rate.

When the variable thermal design flow rate is required, the maximum required flow rate is the design point for the PCS pump and system design in consideration of the NPSH margin and coastdown flow rate.

ACKNOWLEDGEMENT

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REFERENCES

[1] Stepanoff, A. J., Centrifugal and Axial Flow Pumps, John Wiley & Sons, New York, 1957.

[2] Stephen L., Impeller Pump, Pergamon Press, 1965.

[3] Gulich, J. F., Centrifugal Pump, Springer, 2007

[4] ANSI/HI 9.6.1-1998, American National Standard for Centrifugal and Vertical Pumps for NPSH Margin, 1998

[5] H. G. Yoon, M. R. Park, I. S. Yoo, S. C. Hwang, Performance and caviation analysis of the mixed flow pump with a change of the stagger angle, Fall meeting of the Korean Society of Mechanical Engineering, 2009.

[6] H. G. Yoon, I. S. Yoo, M. R. Park, E. S. Yoon, A Study of suction performance of inducer with different inlet shapes, Proceeding of the 6th National Congress on Fluids Engineering, 2010, Busan, Korean.

[7] H. G. Yoon, Y. C. Park, K. W. Seo, D. Y. Chi and I. S. Yoo, Prediction Model of the HANARO primary cooling

pump coastdown, Transactions of the Korea Nuclear Society Spring Meeting, 2011, Taebaek, Korean.

[8] H. G. Yoon, K. W. Seo, D. Y. Chi and J. Yoon, Conceptual design of the primary cooling pump in the open-pool type research reactor, Proceeding of the 7th National Congress on Fluids Engineering, 2012, Gyeongju, Korean.

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]
m	Mass of the fluid, [kg/s]
n_s	Specific speed, $\omega\cdot Q_d^{0.5}/(g\cdot H)^{0.75}$, [-]
u	fluid velocity in the pipe, [m/s]
D	Diameter of the impeller outlet, [m]
E_{fluid}	Fluid kinetic energy, $0.5\cdot m\cdot u^2$, [J]
$E_{flywheel}$	Flywheel energy, $0.5\cdot I\cdot\omega^2$, [J]
H	Pump Head at the design point, [m]
NPSH	Net Positive Suction Head, [m]
$NPSH_A$	Available NPSH, [m]
$NPSH_R$	Required NPSH, [m]
P	Pump power, [w]
Q	Flow rate, [m^3/s]
Q_d	Flow rate at the design point, [m^3/s]
V_1	Velocity at the pump inlet, [m/s]
W_{th}	Thermal Power. [w]
λ	$NPSH_A\cdot g/V_1^2$, [-]
σ	$NPSH_R\cdot g/V_1^2$, [-]
φ	Q/Q_d, [-]
ψ	Pressure loss[m]$\cdot g/u_1$, [-]
ω	angular velocity of the impeller, [rad/s]
χ	d/d_1, [-]