Determination of the Design Speed of the Primary Cooling Pump in the Research Reactor

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1. Introduction

An open-pool type research reactor is widely designed in consideration of the reactor operation and accessibility. Reactor structure assembly is generally placed at the pool bottom as shown in Fig. 1. Primary cooling system circulates the coolant from the reactor core to the heat exchanger. Therefore the heat generated from the reactor core is continuously removed.

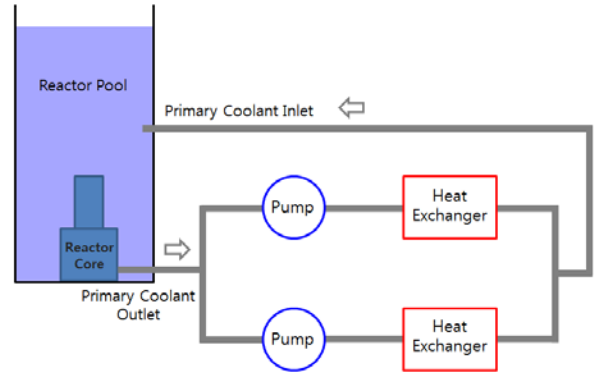

Fig. 1. Schematic diagram of the open-pool type research reactor and the flow path of the coolant

After the primary cooling pumps stop, the decay heat is removed by the coastdown flow induced by the inertia force of a flywheel attached to each primary cooling pump. A pump coastdown flow means that the pump operates with the angular momentums of the shaft, impeller, and flywheel when a loss of electricity occurs.

The primary cooling pump consists of the pump, flywheel, and motor as shown in Fig. 2. They are connected by flexible couplings.

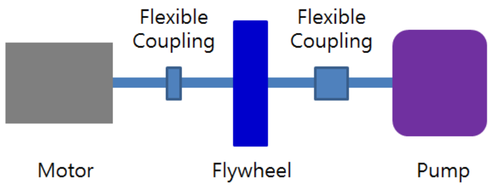

Fig. 2. Schematic diagram of the Primary Cooling Pump

2. Pump Design

The primary cooling pump is designed based on the required thermal design flow rate and system resistance curve. The hydraulic performance and mechanical integrity shall be also considered in the pump design.

2.1 Hydraulic Performance

The pump rated head, flow rate, and $NPSH_A$ are calculated in the system design stage. Then, the pump type is conceptually designed using these variables and the pump specific speed. The pump specific speed is calculated from the flow rate, head, and rotational speed. Therefore, the rotating speed of the pump is the design variable because the flow rate and head are fixed values. Available centrifugal pumps are summarized in Table 1.

Table 1. Conceptual design results of the pump

Case	n_s[-]	d_s[-]	$NPSH_R$	RPM
Case 1	0.59	4.94	2.5m	w_1
Case 2	0.89	3.54	3.5m	w_2

Cavitation in the pump suction, NPSH margin, slope of the pump performance curve, and efficiency are also comprehensively considered. The operating motor speed of Case 2 is about twice as fast as that of Case 1 because the operating motor speed of the AC motor is calculated from the frequency, motor phases, and slip rate as the following equation.

$$N = \frac{120f\left(1-\frac{S}{100}\right)}{P} \quad (1)$$

The Synchronous motor speed is simply calculated in equation (1) with a slip rate of zero. Variable motor speed with the inverter is not considered in this research.

2.2 Pump Coastdown

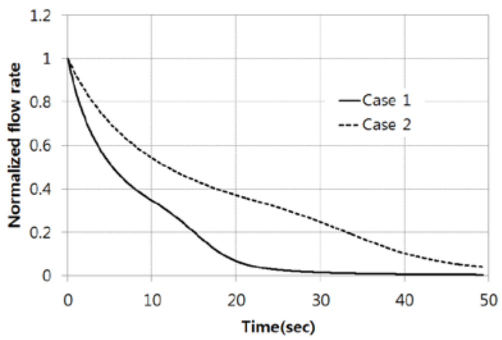

Fig. 3. Coastdown flow rate

The coastdown time is in proportion to the angular velocity and moment of inertia of the rotating part. The angular velocity is obtained from Table 1. The moment of inertia is calculated from the geometry and density of all rotating parts including the flywheel.

Figure 3 shows the calculated coastdown flow rate with different angular velocities, w_1 and w_2 in Table 1. These two curves satisfy the required coastdown flow rate.

3. Mechanical Design

3.1 Flywheel

The flywheel of the primary cooling pump shall be conservatively designed to prevent possible damage to the primary cooling system and the reactor building. The design limits of the flywheel are as follows:

a. The flywheel assembly, including an anti-reverse rotation device, the shaft and the bearings should be designed to withstand normal conditions, anticipated transients, the design basis accidents and the safe shutdown earthquake loads without a loss of structural integrity.

b. The design speed should be at least 125% of normal speed. Normal speed is defined as the synchronous speed of the AC drive motor.

c. An analysis should be conducted to predict the critical speed for ductile, non-ductile fracture and excessive deformation of the flywheel. The normal speed should be less than one-half of the lowest critical speed.

d. The design speed should be at least ten percent above the highest anticipated overspeed. The anticipated overspeed should include consideration of the maximum rotational speed of the flywheel with a loss of coolant accident.

Case 1 pump satisfies the flywheel design limits. However, Case 2 pump does not meet the flywheel design limits.

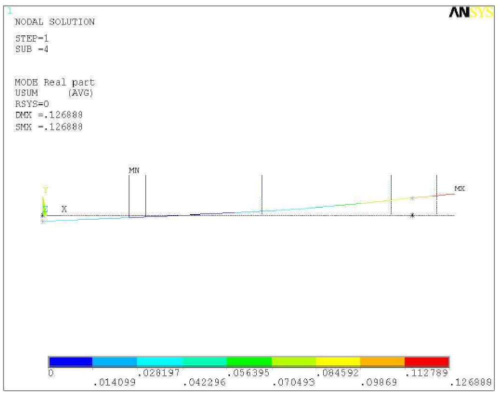

Fig. 4. First mode shape of the pump rotor

3.2 Shaft dynamic

In the shaft design, there shall be a margin of at least ±25% between the rated operating speed and the dry-bending critical speed. Pump start-up operation with the flywheel shall be taken into consideration when the shaft is designed. The critical speed shall include the effects of lubrication, bearings, bearing supports and couplings.

Figure 4 shows the first mode shape of the pump rotor assembly. Case 1 pump satisfies the shaft design requirements. However, Case 2 pump does not meet the shaft design requirements.

4. Conclusions

The primary cooling pump is conceptually designed based on the required flow rate and system constraints. A centrifugal pump of Case 1 with a non-dimensional specific speed of 0.59 [-] and specific diameter of 4.94 [-] is chosen as the primary cooling pump based on the hydraulic performance and mechanical integrity.

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Nomenclature

d_s	Specific diameter, $D\cdot(g\cdot H_d)^{0.25}/Q_d^{0.5}$, [-]
g	Acceleration of gravity, 9.81[m/s^2]
n_s	Specific speed, $\omega\cdot Q_d^{0.5}/(g\cdot H_d)^{0.75}$, [-]
D	Diameter of the impeller outlet, [m]
f	Frequency, [Hz]
H_d	Pump head at the design point, [m]
N	Revolutions per minutes, [rpm]
N_{margin}	NPSH margin, $NPSH_A$ / $NPSH_R$, [-]
NPSH	Net Positive Suction Head, [m]
$NPSH_A$	Available NPSH, [m]
$NPSH_R$	Required NPSH, [m]
P	Motor Phases, 2, 4, 6, 8 (Even number)
Q_d	Flow rate at the design point, [m^3/s]
Q_{ratio}	Normalized flow rate, Q / Q_d, [-]
S	Slip rate, 2~5%
ω	angular velocity of the impeller, [rad/s]