Pump Coastdown with the Submerged Flywheel

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1. Introduction

The purpose of a research reactor is to use a neutron flux in a reactor core located inside a reactor structure assembly unlike an object of a commercial nuclear power plant to make the electrical power from a fission heat of nuclear fuels. Many research reactors are generally designed as open pool types in consideration of the heat removal of the nuclear fuels, reactor operation and accessibility. Reactor structure assembly is generally placed at the pool bottom as shown in Fig. 1. Primary cooling system pump circulates the coolant from the reactor structure to the heat exchanger in order to continuously remove the heat generated from the reactor core in the research reactor as shown in Fig. 1. The secondary cooling system releases the transferred heat to the atmosphere by the cooling tower.

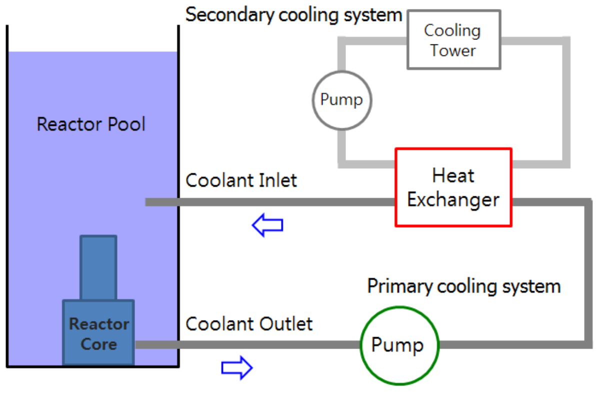

Fig. 1. Schematic diagram of the flow path of the coolant in an open-pool type research reactor

After the primary cooling pumps stop, the core 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. They are connected by flexible couplings as shown in Fig. 2.

When the pipe break accident of the fire water line happened in an equipment room, it is possible that there is an internal flooding. Coastdown flow rate with the submerged flow flywheel is analyzed in this research.

2. Calculation and Results

In the previous research, the primary cooling system pump was designed based on a slope of the pump performance curve, NPSH (Net Positive Suction Head) margin, flywheel design speed and pump size. Centrifugal pump with a non-dimensional specific speed of 0.59 [-] and specific diameter of 4.94 [-] was determined as the primary cooling system pump [1] ~ [3].

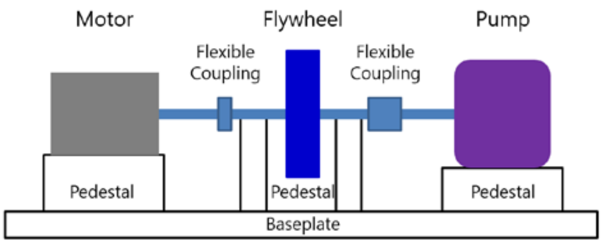

Fig. 2. Schematic drawing of the pump

The primary cooling pumps may stop due to water ingress into the motors when the equipment room is flooded. In this case, lower parts of the flywheels are submerged. There is a high possibility that two motors stop at the same time because height of the pump assembly is same. However, it is assumed that the primary cooling pumps stop simultaneously with fully submerged flywheels for the conservative design.

When the flywheel is submerged, friction load on the flywheel surface shall be considered in the calculation of the coastdown flow rate. There are two kinds of the friction load on the flywheel surface as shown in Fig. 3 [4] ~ [5].

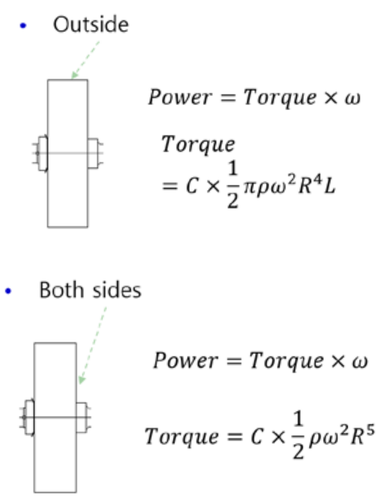

Fig. 3. Friction load on the flywheel surface

Figure 4 shows the calculation diagram of the pump coastdown. Subscripts 'd' and 'i' in Fig. 4 indicated normal operation conditions and the iteration number of the calculation, respectively. This calculation flow chart explains the energy transform from the flywheel to the pump hydraulic energy and friction load on the flywheel. It is assumed that affinity laws of the pump are satisfied in the overall pump coastdown range.

$$\alpha_i = \frac{P_d + P_f}{I\omega_d} = \frac{\dot{m}_d g h_d/\eta_h + P_f}{I\omega_d}$$

$$\downarrow$$

$$\omega_i = \omega_d + \alpha_i \Delta t$$

$$\downarrow$$

$$P_i = (P_d + P_f)\left(\frac{\omega_i}{\omega_d}\right)^3$$

$$\downarrow$$

$$\alpha_{i+1} = \frac{P_i}{I\omega_i}$$

$$\downarrow$$

$$\omega_{i+1} = \omega_i + \alpha_{i+1}\Delta t$$

$$\downarrow$$

$$P_{i+1} = (P_d + P_f)\left(\frac{\omega_{i+1}}{\omega_d}\right)^3$$

Fig. 4. Calculation diagram

Pump coastdown flow rate with the submerged flywheel is calculated by using the affinity laws of the pump and the angular momentum of the flywheel [6] ~ [7]. Figure 5 show the calculated coastdown flow rate with the elapsed time. A half of the normal flow is reached in 5 sec.

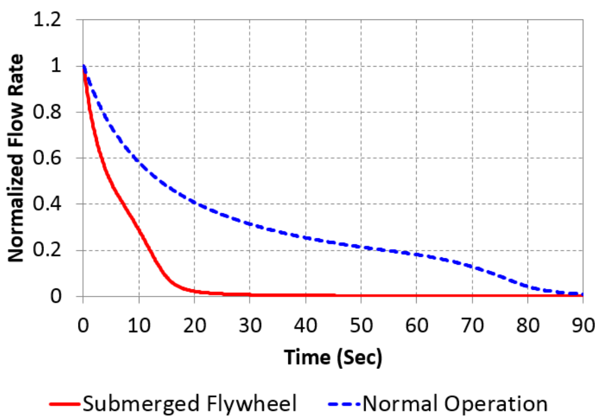

Fig. 5. Coastdown flow rate

4. Conclusions

Coastdown flow rate of the primary cooling system pump with the submerged flywheel are calculated analytically in case of the accident situation. Coastdown flow rate is maintained until almost 80 sec when the pump stops normally. But, coastdown flow rate is rapidly decreased when the flywheel is submerged because of the friction load on the flywheel surface.

Acknowledgement

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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]
h	Pump head, [m]
h_d	Pump head at the design point, [m]
I	Moment of inertia, [kg·m^2]
$\dot{m}$	Mass flow rate, [kg/s]
N	Revolutions per minutes, [rpm]
P	Power, [kW]
P_d	Pump power at the design point, [kW]
P_f	Flywheel friction load at the design point, [kW]
Q	Flow rate, [m^3/s]
Q_d	Flow rate at the design point, [m^3/s]
Q_{ratio}	Normalized flow rate, Q / Q_d, [-]
Δt	Time step, [sec]
α	Angular acceleration, [rad/s^2]
ω	Angular velocity, [rad/s]
η_h	Pump hydraulic efficiency, [-]