Prediction Model of the HANARO primary cooling pump coastdown

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1. Introduction

Pump coastdown means the pump operation the angular momentum of the shaft, impeller and flywheel if loss of off-site power occurs. At this time, flow rate decreases slowly by effect of the moment of inertia and therefore core cooling is continued smoothly.

2. Prediction model and Results

The modified hydraulic efficiency model for the HANARO primary cooling pump coastdown was developed and evaluated with the field data.

2.1 Pump Specification

Type of the primary cooling pump of HANARO is the typical centrifugal pump with the specific speed of 315[rpm,m^3/min,m] and the specific diameter of 0.31[m,m^3/min,m]. In this pump, flywheel is connected with the rotating shaft and located at the back of the electric motor and its moment of inertia, I, is 156.9kg-m^2. The moment of inertia of the shaft and impeller was not considered in this simulation because its value was relatively small compared to that of the flywheel.

2.2 Pump Coastdown

When loss of off-site power occurs, the primary cooling pump starts to operate with the power of the flywheel. At this time, the flywheel has the angular momentum directly proportional to its moments of inertia and angular velocity of the pump impeller. The flywheel supplies the break horse power to the pump through the connected shaft. Initial supplied power was decided from the normal operation conditions of the pump. Mass flow rate, total head raise, angular velocity and hydraulic efficiency of the normal operation are used as initial conditions to calculate the coastdown. Figure 1 shows the calculation diagram of the pump coastdown. Subscripts 'd' and 'i' in Fig. 1 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. It is assumed that affinity laws of the pump are satisfied in the overall pump coastdown range and impeller diameter is the constant [1]. But, the hydraulic efficiency of the pump is got worse when the impeller rotating speed is gradually decreased.

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

↓

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

↓

$$P_i = P_d \left(\frac{\omega_i}{\omega_d} \right)^3 = \dot{m}_d g h_d \left(\frac{\omega_i}{\omega_d} \right)^3$$

↓

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

↓

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

↓

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

Affinity laws of the pump

$$\begin{cases} \text{Flow rate}: Q \propto ND^3 \\ \text{Head}: gH \propto N^2 D^2 \\ \text{Power}: P \propto \rho N^3 D^5 \end{cases}, \quad \begin{cases} N = \text{Rotational speed} \\ D = \text{Impeller diameter} \end{cases}$$

NOTATION

P : Pump power, h : Total head raise
$\dot{m}$: Mass flow rate, g : Gravity acceleration
ω : Angular velocity, α : Angular acceleration
η : Hydraulic efficiency, Δt : Time step
I : Moment of inertia of the flywheel

Fig. 1. Calculation diagram of the coastdown

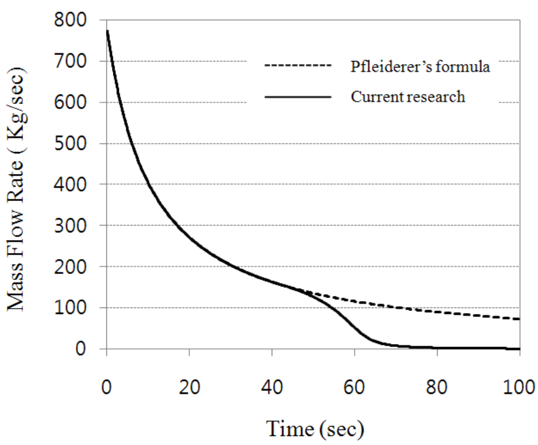

Fig. 2. Coastdown of the pump with time

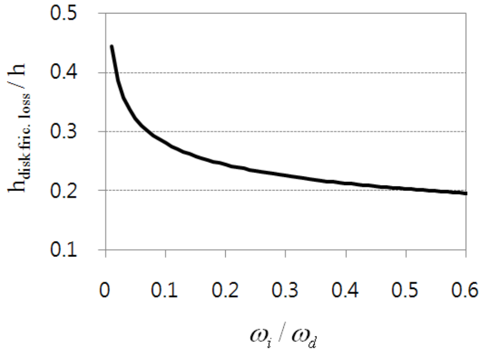

Fig. 3. The proportion of the disk fiction loss to the pump head raise with the impeller rotating speed.

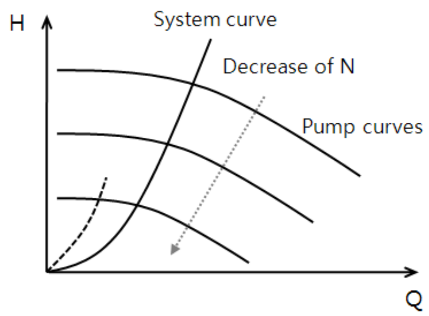

Fig. 4. Change of the system resistance curve with the decrease of the flow rate

Generally, the hydraulic efficiency of the pump is related to the Reynolds number and impeller diameter as Pfleiderer's formula described in Eq. (1) [2].

$$\eta_h = 1-(1-\eta_d)\left(\frac{\omega_d}{\omega_i}\right)^{0.1}\left(\frac{D_d}{D_i}\right)^{0.25}, \quad \frac{1}{15} < \frac{\omega_i}{\omega_d} < 15 \qquad (1)$$

The dotted line in Fig.2 shows the pump coastdown using this hydraulic efficiency equation based on the calculation diagram in Fig. 1. The coastdown is not stopped after 100sec. But, the primary cooling pump coastdown in HANARO is continued until about 70~80 sec from the field data. Thus, the hydraulic efficiency model for the row rotating speed compared to the normal operation is necessary to predict the coastdown accurately.

2.3 Hydraulic Efficiency model for pump coastdown

The decreases of the hydraulic efficiency of the pump during the coastdown are mainly related to disk friction loss of the pump and the increase of the system resistance curve while the rotating speed is deceased [2~5].

The proportion of the disk friction loss to the pump head raise is increased rapidly when the impeller rotating speed is decreased as shown in Fig. 3. And the slope of the system resistance curve is steeper in the row flow rate region because of the increase of the friction loss. It shifts the operating point of the pump from the rated region to the row flow rate region as explained in Fig. 4. These two factors decrease the hydraulic efficiency of the pump. In this research, the modified hydraulic efficiency model is suggested as Eq. (2) based on the Pfleiderer's model.

$$\eta_h = 1-(1-\eta_d)\left(\frac{\omega_d}{\omega_i}\right)^{0.1}\left(\frac{D_d}{D_i}\right)^{0.25} \text{ when } 0.2 < \frac{\omega_i}{\omega_d} < 1$$

$$\eta_h = 1-(1-\eta_d)\left(\frac{\omega_d}{\omega_i}\right)^{0.1}\left(\frac{D_d}{D_i}\right)^{0.25} \times \exp\left(-25\left(0.2-\frac{\omega_i}{\omega_d}\right)\right)$$

$$\text{when } 0 < \frac{\omega_i}{\omega_d} < 0.2 \qquad (2)$$

In equation (2), the model constant '-25' is selected based on the coastdown time of the HANARO. The solid line in Fig.2 shows the pump coastdown using this modified hydraulic efficiency equation. The pump stopped at about 70sec.

3. Conclusions

The pump coastdown mechanism is explained by using the affinity laws of the pump and the angular momentum of the flywheel. And, modified hydraulic efficiency model is suggested to predict the continuous time of the coastdown. This equation will be evaluated and developed through the comparative study with the various experimental data.

REFERENCES

[1] S. L. Dixon, Fluid Mechanics Thermodynamics of Turbomachinery, Elsevier, New York, p. 6-10

[2] Stephen Lazarkiewicz, Impeller Pumps, Pergamon press, New York, p. 615-618, 1965

[3] H. W. Oh, M. K. Chung, Optimum values of design variables versus specific speed for centrifugal pumps, Proc. Instn. Mech Engrs., Vol. 213, Part A, p. 219-226, 1999

[4] J. W. Daily, R. E. Nece, Chamber dimension effects on induced flow and frictional resistance of enclosed rotating disks, ASME Trans. J. Basis Eng., Vol. 82, p. 217-232, 1960

[5] R. B. Munson, D. F. Young, T. H. Okiishi, Fundamentals of Fluid Mechanics, John Wiley & Sons, 4th edition, p. 473-480, 2002