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Hydraulic Performance Requirements in the PHTS Pump of Sodium-cooled Fast Reactor

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1. Introduction

KAERI is currently establishing the design concept for a pool-type Sodium-cooled Fast Reactor (SFR) with 150MWe. Among the several major components, the pump of the Primary Heat Transport System (PHTS) is very important to decide the cooling capacity of the SFR. To determine the hydraulic performance requirements of the PHTS pump, the design specifications of the PHTS pump under nominal operating conditions are produced and the optimal, maximum, and minimum design flow rates in consideration of the system uncertainty are determined by using the methodology of the YGN 3 & 4[1].

2. Methods and Results

The system resistance curve and the performance curve of the pump are required to determine the hydraulic performance requirements of the PHTS pump. The detailed pump performance curve is obtained by the pump manufacturer and the system resistance curve is obtained by calculating the system resistance. The upper limit of the flow rate is determined in consideration of the minimum system resistance and the lower limit of flow rate is determined in consideration of the maximum system resistance and the uncertainty of the measurement. The determination method of the hydraulic performance of a pump is shown in Fig. 1.

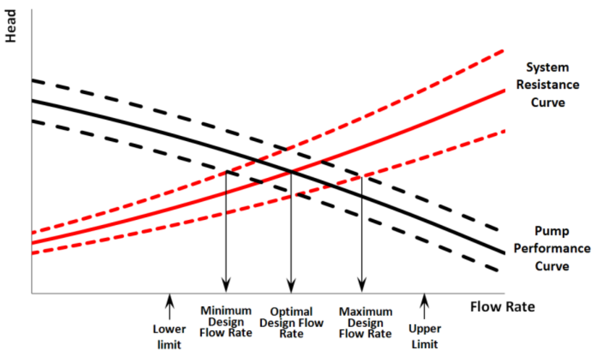

Fig. 1. The determination of the hydraulic performance of a pump

2.1 H-Q Curve of the PHTS Pump

In determining the hydraulic performance requirements of the PHTS pump, the required major assumptions are as follows.

- Corrosion products : none
- Flow measurement uncertainty : 4%
- System resistance uncertainty : 10%
- Pump bypass flow rate : 4%
- Flow and head uncertainty of H-Q curve : 1%, 0.2%

The flow rate and head at nominal operating conditions are 4,176m^3/h and 59.4m, respectively[2]. Also, the deviations of the flow rate and head owing to the uncertainty of the H-Q curve are ±41.76m^3/h and ±0.1188m, respectively. The H-Q curve in a given design point is shown in Eq. (1), and this curve represents a tangent line at the design point about the pump performance curve which is received from the pump manufacturer.

$$H(Q) = -0.00623Q + 85.41648 \tag{1}$$

Also, the maximum and minimum values of the performance curve are straight lines that have the same slope and pass through the point adding or subtracting the uncertainty deviation of the H-Q curve in the design point. Thus, the maximum and minimum H-Q curves are shown in Eq. (2) and (3).

$$H_{max}(Q) = -0.00623Q + 85.7957 \tag{2}$$
$$H_{min}(Q) = -0.00623Q + 85.0378 \tag{3}$$

2.2 System Resistance Curve

The pressure drop of the PHTS in a nominal operating condition is 418.8 kPa[3]. When the system resistance curves are defined by $H_{sys}=CQ^2$, the system resistance curves in a nominal operating condition, which is considered the system resistance uncertainty (10%) are as follows.

$$C_{sys,BE} = 2.908E\text{-}6, \quad H_{sys,BE} = C_{sys,BE}Q^2 \tag{4}$$
$$C_{sys,UB} = 1.1 \times C_{sys,BE}, \quad H_{sys,UB} = C_{sys,UB}Q^2 \tag{5}$$
$$C_{sys,LB} = 0.9 \times C_{sys,BE}, \quad H_{sys,LB} = C_{sys,LB}Q^2 \tag{6}$$

2.3 Determination of the Hydraulic Performance Requirements of the PHTS Pump

The optimal design flow rate is 110.6% of the design point flow rate (included pump bypass flow (4%)) and it can be converted to 4,621m^3/h. Also, the head is 57.67m. These are the values at the point at which the optimal system resistance curve ($H_{sys,BE}$) meets the performance curve of the pump at the design point (*H*). The pressure loss at the entrance and exit of a pump is not included in this value and it should be accommodated in the pump itself.

The minimum design flow rate is 102.3%, and the head is 58.41m. These are the values at the point at which the upper band system resistance curve ($H_{sys,UB}$) meets the minimum pump performance curve (H_{min}). The lower limit of the flow rate is 98.3% (excluded measurement uncertainty (4%)) of the design point and can be converted to 4,107m^3/h.

The maximum design flow rate is 111.5%, and the head is 56.78m. These are the values at the point at which the lower band system resistance curve ($H_{sys,LB}$) meets the maximum pump performance curve (H_{max}). The upper limit of the flow rate is 115.5% (included measurement uncertainty (4%)) of the design point, and can be converted 4,825m^3/h. But the upper limit of flow rate to be used in an existing PWR is 115%, and it is necessary to modify the performance curve of the pump.

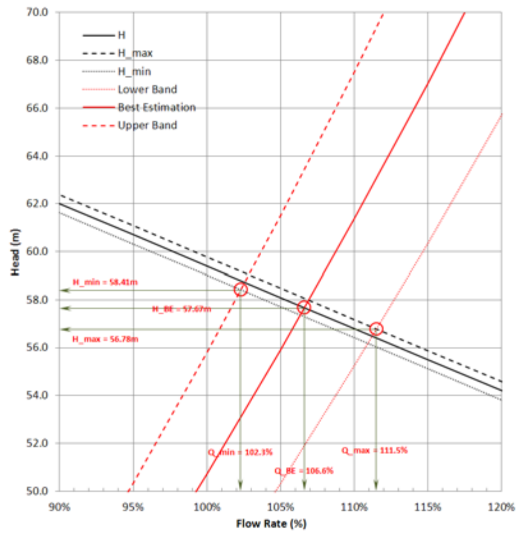

Fig. 2. H-Q curve and system resistance curve of the PHTS pump

2.4 Modification of the Performance Curve of the Pump

To modify the performance curve of the pump, it is much easier to modify only the y-intercept of the performance curve in the position of the pump manufacturer. To modify the slope of the performance curve, the whole pump design must be modified. However, if the y-intercept of the performance curve is modified only, it can be achieved to carve the outer diameter of the impeller. Therefore, the maximum design flow rate, which is excluded as a measurement uncertainty must be 111%. The adjusted *H*, H_{min}, H_{max} using the head at this point are shown in Eq. (7)-(9).

$$H(Q) = -0.00623Q + 84.72475 \quad (7)$$
$$H_{max}(Q) = -0.00623Q + 85.10397 \quad (8)$$
$$H_{min}(Q) = -0.00623Q + 84.34604 \quad (9)$$

The modified optimal design flow rate using Eq. (7) is 110.1% (included pump bypass flow (4%)) and can be converted to 4,599m^3/h. Also, the head is 57.11m.

The minimum design flow rate is 101.8% and the head is 57.85m. The lower limit of flow rate is 97.8% (excluded measurement uncertainty (4%)) of the design point, and can be converted to 4,086m^3/h.

The maximum design flow rate is 110.0% and the head is 56.23m. The upper limit of flow rate is 115.0% (included measurement uncertainty (4%)) of the design point, and can be converted to 4,802m^3/h.

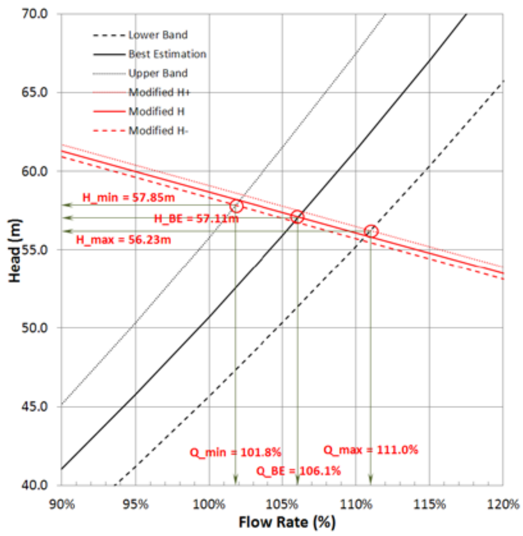

Fig. 3. Modified H-Q curve and system resistance curve of the PHTS pump

3. Conclusions

The hydraulic performance requirements in the PHTS pump of SFR is determined using the methodology of the YGN 3 & 4. The optimal flow rate and the head of the PHTS pump are 4,599m^3/h and 57.11m. These values are 110.1% of the flow rate at the design point and include the bypass flow of the PHTS pump. The allowable flow band for the operation is shown in Fig. 4.

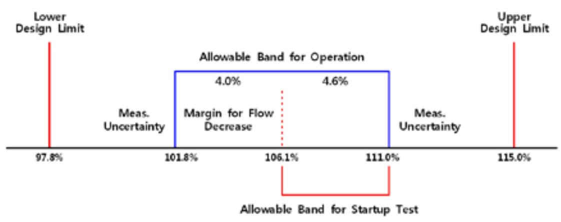

Fig. 4. Allowable flow band for operation

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[3] J. Yoon, The Calculation Sheet of the Pressure for the PHTS Pump, KAERI, 2012.