Preliminary Design of Primary Heat Transport System Pump in SFR with 3800 MWt

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1. Introduction

SFR (Sodium-cooled Fast Reactor) is one of a next-generation nuclear power reactor that can effectively process spent nuclear fuel. Since the SFR uses liquid sodium as a coolant and sodium has a high boiling temperature, high operating pressure is not required, and hence, the design pressure for components inside the reactor is nearly atmospheric. In addition, sodium has high thermal conductivity, and hence, a pool-type SFR, in particular, can effectively remove the heat generated in the reactor.

KAERI (Korea Atomic Energy Research Institute) has performed a conceptual design of the PGSFR (Prototype Gen-IV Sodium-cooled Fast Reactor) [1]. KAERI has also performed a preliminary design of a pool-type SFR which consists of PHTS (Primary Heat Transport System), IHTS (Intermediate Heat Transport System) and DHRS (Decay Heat Removal System) [2]. This SFR has TRU core and the capacity of 3800 MWt.

In this study, a preliminary design of the PHTS pump in SFR with 3800 MWt is presented. A methodology of determining the geometric parameters and design conditions of pump is addressed.

2. Methods and Results

2.1 Pump type selection

The function of the PHTS pump in SFR is to move sodium from the cold pool to the hot pool through the core, and circulate it back to the cold pool through the intermediate heat exchanger. The pump should be designed to maintain hydraulic performance and mechanical stability in all operating modes including normal operation.

The types of pumps used in SFR include mechanical or electromagnetic pumps. The mechanical pump mainly uses a vertical centrifugal type in the PHTS of SFR as shown in Fig. 1. The mechanical pump consists of a rotating impeller and a stationary diffuser and housing. In the mechanical pump, a long rotating shaft passes through the reactor head, and a motor is connected to the rotating shaft above the reactor head. In addition, bearings are used to support the rotating shaft, and seals are used to prevent leakage.

The electromagnetic pump uses the conductivity of liquid metal and has no rotating parts. Therefore, the electromagnetic pump does not require bearings or seals and has a simple structure, so it is widely used in SFR. Figure 2 shows schematic of the electromagnetic pump.

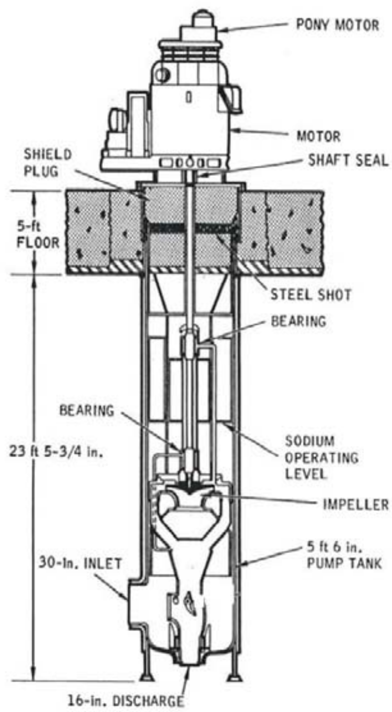

Fig. 1 Schematic of mechanical pump

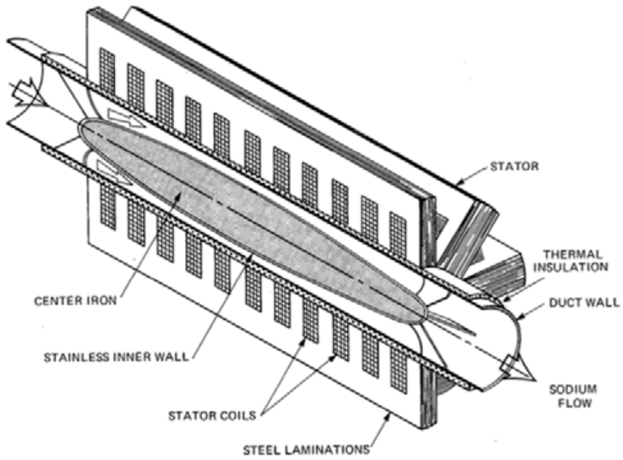

Fig. 2 Schematic of electromagnetic pump

Mechanical pumps and electromagnetic pumps each have their pros and cons. While mechanical pumps have large technology base and experience for SFR, they require a lot of maintenance due to bearings or seals. On the other hand, electromagnetic pumps do not require much maintenance and are stable. However, the efficiency is low, and flow instability may appear at high flow rates. Design features of mechanical and electromagnetic pumps are summarized in Table 1.

Table 1. Design features of mechanical and electromagnetic pumps

	Advantages	Disadvantages
Mechanical pump	- High efficiency - High flow rates - Large technology base for SFR	- Cavitation - Bearing - Sealing - Maintenance
Electromagnetic pump	- Simple design - No maintenance - Good stability - No cavitation	- Low efficiency - Little experience with large flow rate pump - Potential flow instability for large flow rate pump

In this study, the type of pump was determined as mechanical pump because the flow rate of the PHTS is high.

2.2 Pump design parameters

The design requirements of the PHTS pump in SFR with 3800 MWt are as follows.

- Flow rate: 457 m^3/min
- Head: 65 m

The flow rate is determined by the heat balance for the PHTS, and the head is determined by the pressure loss generated in the PHTS. After the flow rate and head of the pump are determined, the rotational speed of the pump should be determined. There are two general methods for determining the rotational speed of the pump. First, there is a method to calculate the synchronous speed of the motor using the number of poles and the frequency of the motor. Second, there is a method of determining the rotational speed by selecting a specific speed so that the efficiency of the pump is highest. However, in this study, the rotational speed of the pump was determined considering the size of the pump and the immersion depth of the impeller.

Since the size of the pump has a great influence on determining the size of the reactor, the size of the pump should not be excessively large. The size of the pump can be obtained through the following process. When the rotational number of the pump is determined, the outer diameter of the impeller is determined and the diameter of the pump casing is determined in consideration of the diffuser. Finally, the size of the pump is determined by the diameter of the inlet bell installed outside the pump casing (Fig. 3). The diameter of the inlet bell was designed in the following way. Pump intake refers to the annular space between the pump casing and the inlet bell, and it should have an inlet velocity that does not cause vortex at the intake. The diameter of the inlet bell is determined to have that value.

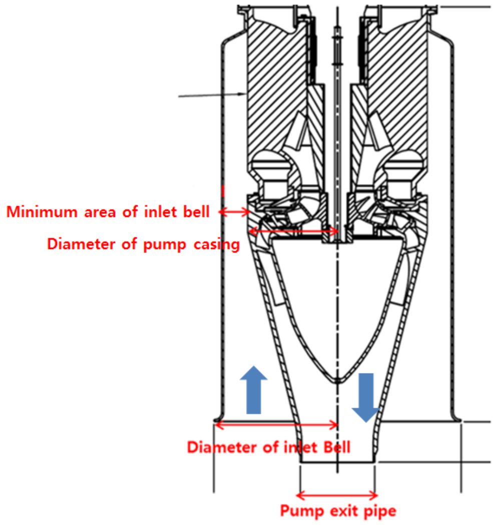

Fig. 3 Geometry of the PHTS pump

The $NPSH_R$ (Required Net Positive Suction Head), one of the design requirements of the pump, means the suction head required to operate without cavitation, and can be obtained through the following equations.

$$\sigma = \frac{NPSH_R}{H} \quad (1)$$

$$\sigma = 7.88 \times 10^{-5} N_S^{\frac{4}{3}} \text{ (single suction)} \quad (2)$$

$$\sigma = 5.00 \times 10^{-5} N_S^{\frac{4}{3}} \text{ (double suction)} \quad (3)$$

Where σ is the Thoma's cavitation factor, and N_s is the specific speed. The rotational speed of the pump affects the $NPSH_R$ and determines the immersion depth of the impeller where cavitation does not occur.

In order to determine the rotational speed of the pump, a parametric study was performed on the diameter of the inlet bell and the immersion depth of the impeller according to the rotational speed. Figure 4 shows the change in the diameter of the pump inlet bell according to the rotational speed. It can be seen that the diameter of the pump inlet bell decreases as the rotational speed increases. The $NPSH_A$ (Available Net Positive Suction Head) for stable operation of general commercial pumps usually uses 1.3 times the $NPSH_R$, but for a conservative design, it was set to 2 times to calculate the immersion depth of the impeller. Figure 5 shows the change in the immersion depth of the impeller according to the rotational speed. It can be seen that the immersion depth of the impeller increases as the rotational speed increases.

The diameter of the inlet bell affects the diameter of the reactor and the immersion depth of the impeller affects the height of the reactor. Considering the change in the inlet bell diameter and impeller immersion depth according to the rotational speed, the rotational speed of the pump was selected as 500 rpm. Pump design parameters are summarized in Table 2.

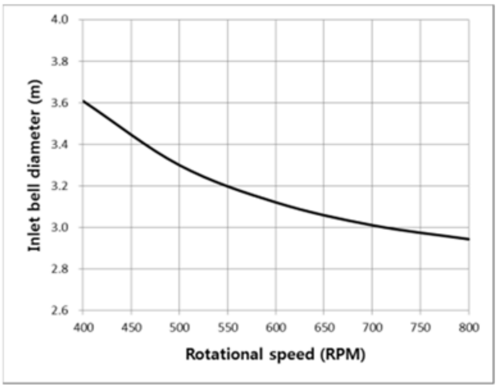

Fig. 4 Change in diameter of inlet bell according to the rotational speed

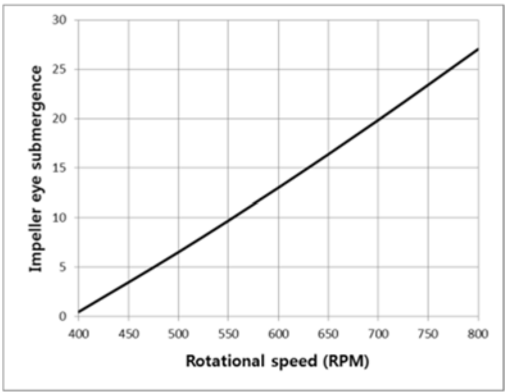

Fig. 5 Change in impeller eye submergence according to the rotational speed

Table 2. Design parameters of the pump

Parameters	Value
Flow rate	457 m^3/min
Head	65 m
Rotational speed	500 rpm
Specific speed	468
Efficiency	80
Inlet bell diameter	3.3 m
Impeller eye submergence	6.5 m

3. Conclusions

A preliminary design of the PHTS pump in SFR with the capacity of 3800 MWt was performed. The type of pump was determined as mechanical pump because the flow rate of the PHTS is high. A methodology of determining the design parameters of the PHTS pump was presented. In order to determine the rotational speed of the pump, a parametric study was performed on the diameter of the inlet bell and the immersion depth of the impeller according to the rotational speed.

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