Flow Characteristics of the PHTS Mechanical Pump in PGSFR

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1. Introduction

The PHTS (Primary Heat Transfer System) mechanical pump is one of the most important parts in the PGSFR. The objective of the PHTS pump is to circulate a sodium coolant to transfer the heat generated in the core to the IHTS (Intermediate Heat Transfer System). Therefore, it is important to verify the performance of the PHTS pump under various flow conditions. The flow inside the pump is a very complex multi-dimensional phenomenon that depends on the rotation speed of the pump, and the geometry of the impeller and diffuser. In particular, the pump performance and flow characteristics can be evaluated using a homologous curve represented by normalized variables of the head and torque.

Using a homologous curve obtained by a real pump or model pump reduced by the same specific speed is reasonable, but the detailed design procedure about the prototype PHTS pump has not been completed at this point. In this study, the flow characteristics and homologous curve of the PHTS pump are evaluated by CFD.

2. Methods

2.1 Geometry

A schematic and flow path of a PHTS pump are shown in Fig. 1. The analysis domain consists of an inlet, casing, impeller, diffuser, piping, and outlet. The flow sucked from the pump outside by the rotation of the impeller is discharged through the diffuser and piping connected to the outlet. The assumptions for all analyses are shown below.

- Three-dimensional, Steady-state
- Sodium density and viscosity at 390 ºC are given
- Gravity and temperature are not considered

2.2 Methodology

A numerical analysis is performed by STAR-CCM+ V8.02.011. A three-dimensional steady-state flow is assumed. Sodium properties such as the density and viscosity are given at the value of 390ºC. Also, the standard $k - \epsilon$ cubic turbulence model which has an advantage in that it calculates the velocity at the curved piping well is used, and the total number of computational grids is 14,700,000.
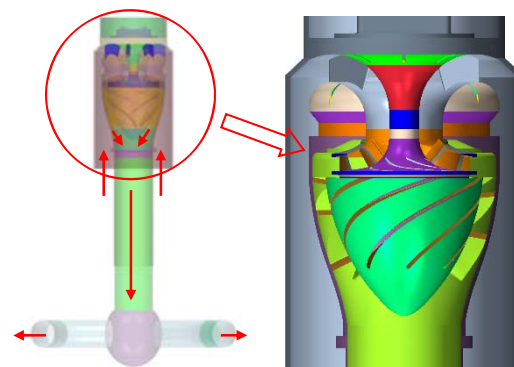

Fig. 1 The schematic and flow path of a PHTS pump

To describe the rotation of the impeller, the Moving Reference Frame (MRF) method is applied. When the rotation speed is constant, the Coriolis and centrifugal forces are treated as a source term in the momentum equation. This method has advantages in which a moving mesh is not needed, and a steady-state analysis is possible. MRF is applied to the impeller region. In addition, rotating and non-rotating faces are treated as the interface.
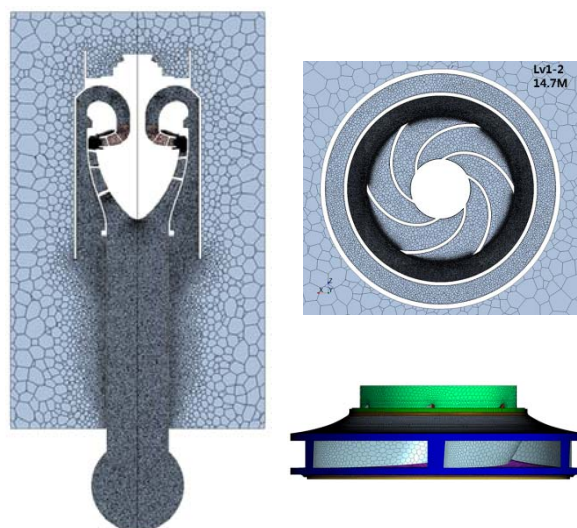

Fig. 2 Detail mesh configuration

2.3 Boundary Condition

The boundary conditions at the rated point are shown in Table 1. The inlet is applied to the pressure boundary, and the outlet is applied to the mass flow inlet boundary in which the flow direction is opposite.

For the validation of the CFD model, a numerical analysis in rated point is performed. The CFD result and design specifications at the rated point are almost same. These results are shown in Table 2 and Fig. 3.

Table I: Boundary Condition at Rated Point

Item	Value
Flow Rate	69.51 m³/min
RPM	750 rpm
Head	73.32 m
Torque	10,825 N-m
Inlet boundary	Pressure
Outlet boundary	Mass flow inlet (-)

Table II: Design Specification and CFD Result Comparison of the PHTS Prototype Pump

Item	Design Spec.	CFD Result	Diff.
Flow Rate	69.51 m³/min	69.51 m³/min	0.0 %
RPM	750 rpm	750 rpm	0.0 %
Head	73.32 m	75.23 m	2.6 %
Torque	10,825 N-m	11,489 N-m	6.1 %

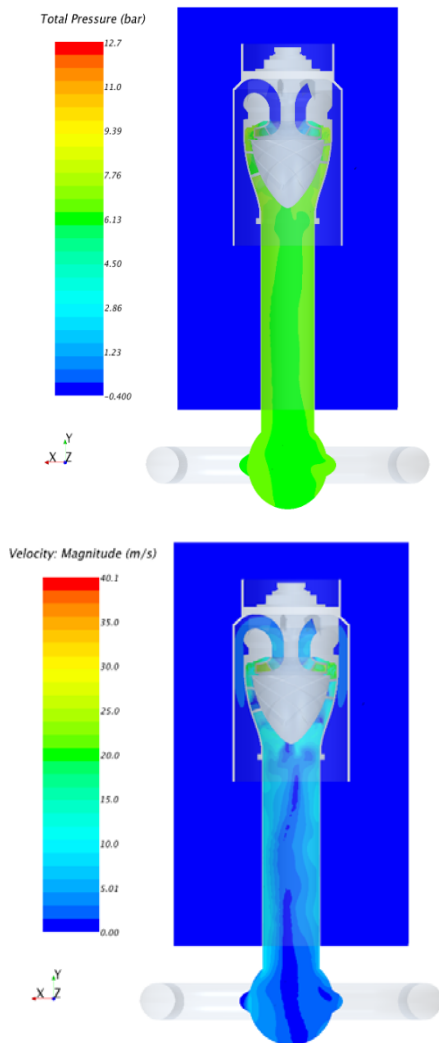Fig.3 Pressure and Velocity Distribution

3. Results

In a homologous curve, normalized pump parameters related to the flow rate Q, torque T, head H, and rotation speed N are defined in a four-quadrant region. An analysis of the fluid systems containing pumps during the transients and an abnormal pump operation requires complete knowledge of the relationships between Q, T, H, and N under a wide range of values for each. These four commonly used quadrant regions are usually defined by the relationship between the direction of the flow and impeller rotation. Each of the variables Q, N, T and H are normalized to the pump rated conditions as follows:

$$\nu = \frac{Q}{Q_R} \tag{1}$$

$$a = \frac{N}{N_R} \tag{2}$$

$$h = \frac{H}{H_R} \tag{3}$$

$$b = \frac{T}{T_R} \tag{4}$$

where ν, a, h and b define the flow rate ratio, speed ratio, head ratio and torque ratio, respectively. Subscript R represents the rated value. A detailed explanation of the four-quadrant region is shown in Fig. 3.

- Normal pump region (Q > 0, N > 0)
: ν/a or a/ν is 0.01 to 1.0 with a step of 0.1 (HAN, HVN)

- Energy dissipation region (Q < 0, N > 0)
: ν/a or a/ν is -0.01 to -1.0 with a step of 0.1 (HAD, HVD)

- Normal turbine region (Q < 0, N < 0)
: ν/a or a/ν is 0.01 to 1.0 with a step of 0.1 (HAT, HVT)

- Reverse pump region (Q > 0, N < 0)
: ν/a or a/ν is -0.01 to -1.0 with a step of 0.1 (HAR, HVR)
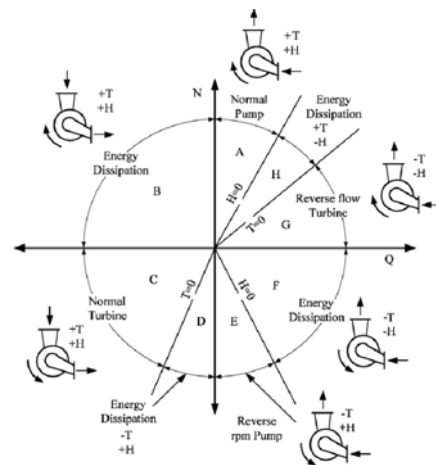

Fig. 3 Characteristics of the Centrifugal pumps

Numerical analyses are performed in order to produce the homologous curve. Four analysis groups are divided according to the flow rate and rotation speed. There are 21 cases in each group. The homologous curve for the head and torque are shown in Fig. 4 and Fig. 5.
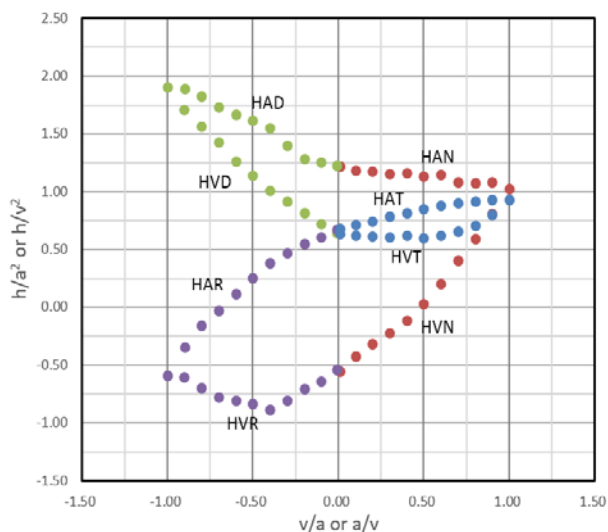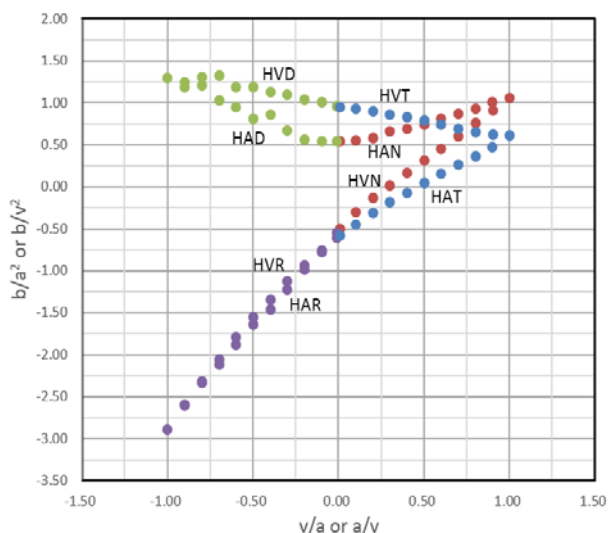

Fig. 4 Homologous Head Curve of PHTS Pump

Fig. 5 Homologous Torque Curve of PHTS Pump

4. Conclusions

The flow characteristic of the PHTS pump is evaluated by the CFD. The head and torque are calculated at several flow rates and rotation speeds, and these values are substituted with normalized pump parameters. Also, the homologous head and torque curve is plotted using normalized pump parameters. This curve is used as the input of the safety analysis.

5. Acknowledgement

REFERENCES

[1] J. Yoon, Preliminary Design Report of the PHTS Prototype Mechanical Pump, KAERI, 2014
[2] J. Yoon, Flow Analysis of the PHTS Prototype Mechanical Pump, KAERI, 2014
[3] K.Y. Choi, Y.S. Kim, S.J. Yi, W.P. Baek, Development of a Pump Performance Model for an Integral Effect Test Facility, Nuclear Engineering and Design, Vol.238, p.2614-2623, 2008.
[4] Y.T. Kim, S.H. Ko, Y.K. Kwack, Y.B. Lee, Numerical Study on the Main Coolant Pump of Sodium-Cooled Fast Reactor, The Korean Society of Mechanical Engineers, p.2058-2062, 2011.