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Structural Pre-sizing of a Coaxial Double-tube Type Hot Gas Duct

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1. Introduction

The nuclear hydrogen system being researched at KAERI is planning to produce hydrogen in the order of 950℃ by using nuclear energy and a thermo-chemical process, and helium gas is tentatively considered as the choice for the coolant. A hot gas duct (HGD) is a key component connecting the reactor pressure vessel and the intermediate heat exchanger (IHX) for the nuclear hydrogen system as shown in Fig. 1. The HGD is a unique component exclusively found in an HTR-module concept where a nuclear core and IHX are placed separately into two pressure vessels, which require a connecting duct between them. A coaxial double-tube type cross vessel is considered for the HGD structure of the nuclear hydrogen system because of its successive extensive experience.

In this study, a structural pre-sizing for the primary HGD was carried out. These activities include a pre-decision on the geometric dimensions, a pre-evaluation on the strength, and a pre-selection on the material of the coaxial double-tube type cross vessel components. A pre-decision on the geometric dimensions was undertaken based on various engineering concepts, such as a constant flow velocity (CFV) model, a constant flow rate (CFR) model, a constant hydraulic head (CHH) model, and finally a heat balanced (HB) model. For the CFV model, CFR model, and CHH model, the HGD structure might be insensitive to a flow induced vibration (FIV) in the case where there are no pressure differences between the hot and cold helium regions. Also we compared the geometric dimensions from the various models.

2. Nuclear Hydrogen System

Two HGDs and an IHX are needed in the nuclear hydrogen system as shown in Fig. 1. One of the HGDs, which is called a primary HGD, is located between the reactor pressure vessel and the IHX. The other HGD, which is called a secondary HGD, is located between the IHX and the SO_3 decomposer. The primary HGD structure of the nuclear hydrogen system is considered as a horizontal coaxial double-tube structure as shown in Fig. 2 which provides a passage for the hot and cold helium gas, while the secondary HGD with a coaxial double-tube structure is one of the tentative candidates.

Table 1 [1] illustrates the tentative design configuration of the nuclear hydrogen system in this study. Based on the tentative design configuration and a preceding research, a preliminary design evaluation for the primary HGD with a coaxial double-tube type cross vessel of the nuclear hydrogen system is carried out.

Table 1 Tentative Design Configuration

Power [MW_t]	200
Pressure boundary of a primary HGD [MPa]	~ 7.0
Inlet/Outlet temperature of helium [℃]	~ 490/950

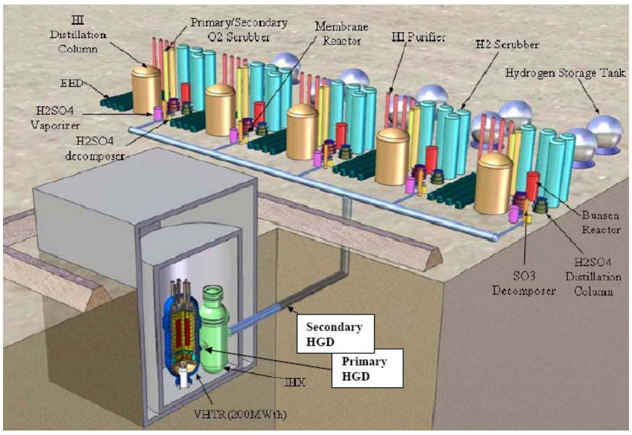

Fig. 1 Nuclear Hydrogen System

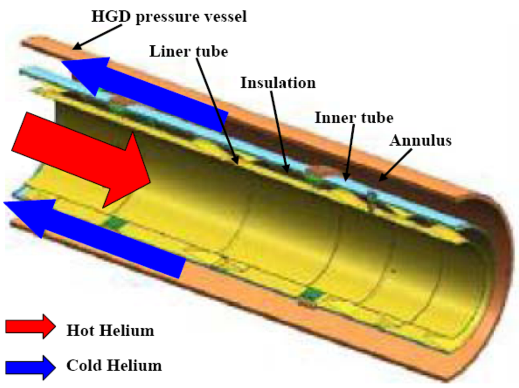

Fig. 2 Structural of the Coaxial Double-tube Type HGD

3. Structural Pre-sizing of the Primary HGD

3.1 Decision of the Inner Diameter of a Liner Tube

The inner diameter of a liner tube is determined by considering the thermal power of the nuclear hydrogen system and the continuity equation as follows.

$$Q = \dot{m}\, C_p\, \Delta T \quad (1)$$

$$\dot{m} = \rho\, AV \quad (2)$$

3.2 Strength evaluation of the Primary HGD Components

At a normal operating condition, the circumferential stresses for the primary HGD components are obtained as follows.

$$\sigma = \frac{PD}{2t} \quad (3)$$

During a loss of the helium pressure of the primary loop, the circumferential stresses for the liner tube and the inner tube are obtained as follows in case that the pressure difference would however not exceed 0.2 MPa.

$$\sigma^* = \frac{(0.2)\,D}{2t} \quad (4)$$

3.3 Engineering Concepts to Reduce the FIV

The inner diameter of the primary HGD pressure vessel is obtained by applying the following engineering concepts for a primary HGD structure with a coaxial double-tube type cross vessel to be insensitive to a flow-induce vibration, i. e. the flow velocity (V), the flow rate (ρV), and the dynamic pressure (1/2 ρV^2) in the liner tube are the same as those in the annulus between the inner tube and the primary HGD pressure vessel as follows.

For CFV model; $V_{out} = V_{in}$ (5)

For CFR model; $(\rho V)_{out} = (\rho V)_{in}$ (6)

For CHH model $(\rho V^2)_{out} = (\rho V^2)_{in}$ (7)

3.4 Heat Balance Model

We considered the heat balance model of the primary HGD as shown in Fig. 3, which D_i and T_i represent the diameter and temperature of each part, respectively. The heat balance of the system is defined as Eq. (8) [2] and the heat transfer coefficient (h) is obtained from the modified Dittus-Boelter model [3] as in Eq. (9).

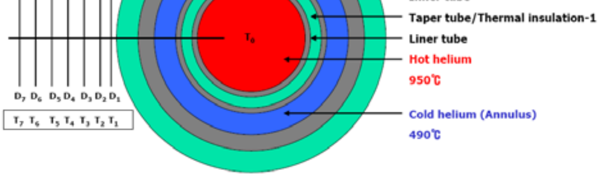

Fig. 3 Cross-section of the primary HGD and its design parameters

$$\dot{Q} = q \bullet \pi \bullet D_7 = h_{He-Hot} \bullet \pi \bullet D_1 \bullet (T_0 - T_1) = \frac{2\pi\, k_{Liner\ tube}}{\ln(D_2/D_1)} \bullet (T_1 - T_2) \quad (8)$$

$$= \frac{2\pi\, k_{Insulation-1}}{\ln(D_3/D_2)} \bullet (T_2 - T_3) = \frac{2\pi\, k_{Inner\ tube}}{\ln(D_4/D_3)} \bullet (T_3 - T_4) = h_{He-Cold} \bullet \pi \bullet D_4 \bullet (T_4 - T_5)$$

$$= \frac{2\pi\, k_{HGD\ press.tube}}{\ln(D_6/D_5)} \bullet (T_5 - T_6) = \frac{2\pi\, k_{Insulation-2}}{\ln(D_7/D_6)} \bullet (T_6 - T_7) = h_{Air} \bullet \pi \bullet D_7 \bullet (T_7 - T_{Air})$$

$$Nu = 0.021\ \mathrm{Re}^{0.8}\ \mathrm{Pr}^{0.4} \quad (9)$$

A heat flux per unit length is assumed to be 25.53 kW/m.

3.5 Results

Table 2 shows the structural pre-sizing results from the three engineering concepts and the heat balance model.

Table 2 Geometric dimensions of the primary HGD

	CFV	CFR	CHH	HB
Liner tube (Alloy 617)				
Inner diameter (mm)	772	772	772	772 (950℃)
Thickness (mm)	7	7	7	7
Inner tube (Alloy 800H)				
Inner diameter (mm)	1,026	1,026	1,026	1,026 (497℃)
Thickness (mm)	10	10	10	10
Annulus				
Inner diameter (mm)	1,046	1,046	1,046	1,046 (493℃)
Outer diameter (mm)	1,211	1,300	1,252	1,316
HGD pressure tube (Mod.9Cr1No)				
Inner diameter (mm)	1,211	1,300	1,252	1,316 (488℃)
Thickness (mm)	60	65	65	65

5. Conclusion

Structural pre-sizing of a primary HGD with a coaxial double-tube type structure for the nuclear hydrogen system is obtained based on various engineering concepts. When compared the geometric data and strength pre-evaluation results for each engineering model, and the geometric dimensions of the primary HGD would be acceptable for the design requirements even if there are some differences in the geometric dimensions of the HGD pressure tube. So it is recommended to use an easy and convenient model in the case of a structural pre-sizing of a primary HGD.

Acknowledgements

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