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The preliminary design of cooling channel for ITER GDC

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ABSTRACT

Just as Diagnostic First Wall (DFW), electrode head will bear strict heat loads. Cooling channel of electrode head is particularly important. In this paper, multilayer cooling channels of electrode head are introduced, and "U" shape route in first layer is adopted to improve the heat exchange. The calculation of the thermal hydraulic and total strain range for optimization results was conducted with ANSYS software, and compared with the data before optimization. The results show that the average surface temperature of electrode head and the total strain range have been greatly reduced. The analysis results shows that the maximum surface temperature of the electrode head decreases from 379.6 °C to 293.2 °C, reduced by 22%. The total strain range decreased from 1.4% to 0.39%, reduced by 72%. However, the strain ranges in two localized regions is from 0.3% to 0.39% where only 9800 cycles can be achieved when strain range is 0.39%. The electrode head design faces challenge of thermal fatigue. Further work should be focused on both the structural optimization and also cooling water parameters improvement.

1. Introduction

A DC (Direct Current) glow discharge system is in preparation for ITER (International Thermonuclear Experimental Reactor) with primary aim to control impurities and particle recycling [1,2]. Since the glow discharge system penetrates the VV (Vacuum Vessel), it is subsequently required to 1 provide the first confinement for radioactive in vessel sources [2,3].

Based on the staged installation strategy of ITER, PE (Permanent Electrode) will be integrated into DPP (Diagnostic Port Plugs) as a part of the assembly. The front surface of electrode head is flush with DFW and the electrode head directly faces plasma. Therefore, electrode head is a unique heat exchanger exposed to plasma radiant heat load of 350 kW/m^2 and peak neutron fluxes of 8 MW/m^3 (equatorial) and 5 MW/m^3 (upper) [4]. Meanwhile, according to the requirements from ITER, the electrode front surface should attain 30k cycles of life. So, the cooling channel design is difficult.

2. PE 12# cooling channel design and calculation boundary condition

On the current design stage, PE in EP 12# will be integrated into a Diagnostic Port Plug (DPP) as a part of the assembly, as shown in Fig. 1. The front surface of electrode head is flushed with DFW. Just as DFW, Electrode head suffers the same heat flux density. The material of PE is ITER SS 316LN-IG.

2.1. The determination basis of flow rate

Flow rate 3 kg/s was provided to each first wall segment in equatorial port. Flow rate of electrode head can be determined in accordance with the proportions of cooling area (DFW: 955 × 513 mm, electrode head: 360 × 200 mm). According to this scale, flow rate ~0.5 kg/s should be used for design and analysis.

2.2. The structural design of cooling channels

ITER diagnostic first wall was originally designed to have a 5 mm-thick first wall panel primarily based on the requirement of total strain range of thermal fatigue, described in the SDC-IC (The Structural Design Criteria for ITER In-vessel Components) documents [5–7]. Recent experimental studies show that the stainless steel first wall panel will melt at a rate of ~1 micrometer/pulse due to the disruption mitigated thermal flashes [8–10]. Decision of using a 6 mm-thick first wall was made based on current DFW design. Electrode head, just as DFW, is under the same environment. So, the thickness of first layer wall of electrode head is 6 mm.

Guided from other ITER in-vessel components (DFW, Divertor & Blanket shielding modules), the limit of the average coolant velocity is about 5m/s. But velocity of some places allows over 5 m/s. So, the average velocity of coolant in electrode head first layer for the design is about 3 m/s.

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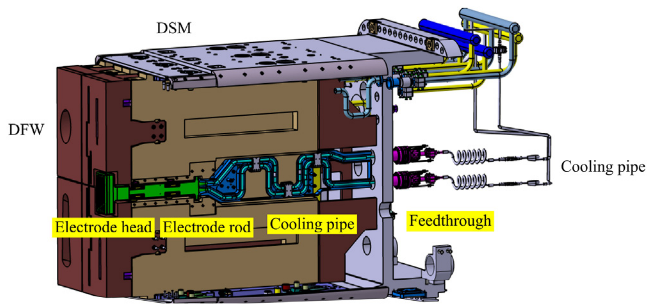

Fig. 1. PE12# inside the Diagnostic Port Plug.

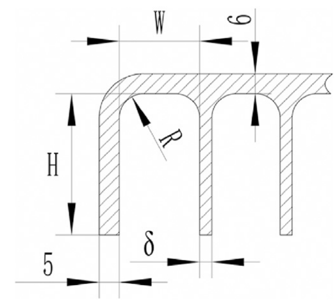

Fig. 3. Basic parameters of the first layer fluid channel.

Table 1
Adjusting the parameter of the first layer fluid channel.

Version	Section size of channel (W × H, mm^2)	Rib thickness (δ, mm)	Corner radius (R, mm)
V1	18 × 12	6	2
V2	19.38 × 12	5	2.5
V3	12.84 × 13.2	4.7	3
V4	12.84 × 13.2	4.7	4
V5	12.5 × 13.2	3.64	2
V6	11 × 15	3.92	3
V7	11 × 15	3.92	3
V8	11 × 15	3.92	3
V9	11 × 15	3.92	3

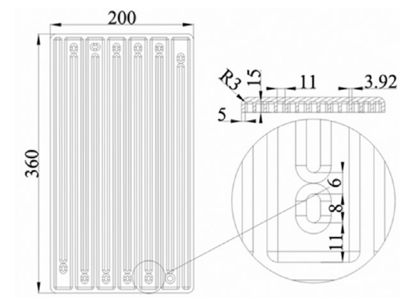

Fig. 4. the structure of first layer fluid channel.

The length, width, and height of the electrode head are 360 mm, 200 mm, and 98 mm respectively. The length of electrode rod is about 780 mm. The head surface area is about 0.072 m^2.The section area of electrode rod is 120 × 80 mm. Since the neutron heating is related to the radial distance, three layers are used for the better absorption of the neutron heating load. At the same time, we hope that three layers can also reduce the temperature of the electrode head. For PE 12#, so far the coolant circuit was segmented into three layer structure, as shown in Fig. 2. The cooling water will go directly from the rod to the first layer because of high heat load caused by plasma radiation and neutron fluxes. After circulating in the first layer the cooling water then goes down to the second layer. Water passes through the second layer and the third layer, then goes back along electrode rod and cooling pipes to the outside of vessel.

Channel section area in the first layer can be estimated, as follow.

$$A = \frac{M}{\rho \times V} \quad (1)$$

Where A is channel section area (mm^2); M is Mass flow rate (0.5 kg/s); ρ is Liquid density (1 × 103 kg/m^3); V is Liquid velocity (3 m/s).

Eq. (1) is solved for A ∼ 167 mm^2. According to adjusting the parameters in Fig. 3 and calculation, we obtain a better fluid channel structure V9 in Table 1. The fluid channel structure of V9 is shown in Fig. 4.

The length, width, and height of the first layer fluid channel are 350 mm, 11 mm, and 15 mm respectively. The thickness of first wall is 6 mm. The thirteen fluid channels are connected by concatenation. We do not need to pay much attention to cooling channel of the second layer and the third layer, because the second layer and the third layer withstand smaller heat load. Average velocity is designed at about 2 m/s. The fluid channels are parallel, as shown in Fig. 5.

2.3. *Loading and boundary conditions*

Two main working conditions including GDC (Glow discharge cleaning) and POS (Plasma Operation State) are considered. Cooling water parameters are given in Table 2. Table 3 shows heat loads for heat transfer calculations.

3. The analyzing and calculating results

3.1. *Thermal hydraulic analysis*

ANSYS CFX is used to run the thermal hydraulic analysis based on the current cooling fluid channel design.

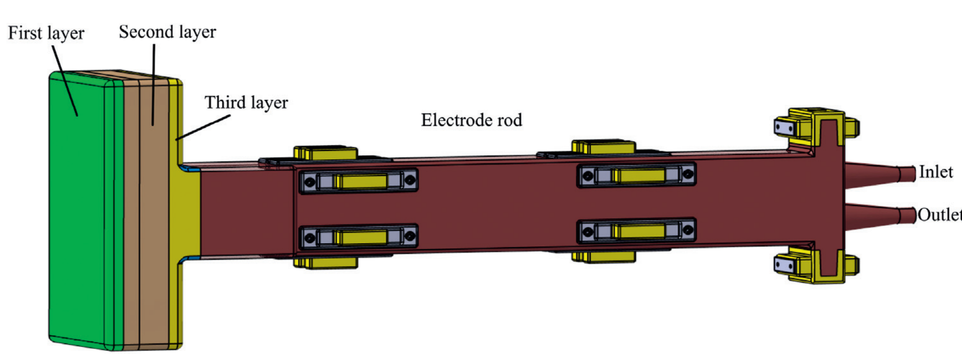

Fig. 2. the three layer fluid channel structure of electrode.