Design Feature and Result of PFCs Baking System for the KSTAR

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1. Introduction

The Korea Superconducting Tokamak Advanced Research (KSTAR) is being majorly updated for 2010's operation which mainly aims to achieve the plasma shaping and diverted plasmas. The Plasma Facing Components (PFCs) such as inboard & outboard limiters, divertors, and passive stabilizers have been finally installed in the vacuum vessel (VV) by middle of June 2010. The baking and cooling (B&C) pipe system for all the PFCs were installed inside of the vacuum vessel to fulfill baking and active cooling of each PFC components [1]. The PFCs are to be baked by circulating hot nitrogen gas through internal tubes of back-plates of the PFCs. While VV is baked-out, the PFCs temperature was raised from room temperature to 120℃, and the baking temperature was raised again to 200℃ in spite of the VV being maintained at room temperature.

2. Plasma Facing Components

As shown in Fig 1, the KSTAR PFCs system is mainly comprised of the inboard limiter, the divertor (which can be divided into inboard, central and outboard divertor), passive stabilizer, poloidal limiter, and neutral beam(NB) protection armor system[1]. All the back-plate of PFCs were made of SS 316LN and copper alloys (CuCrZr) on which graphite tiles are mechanically attached. The back-plates are actively cooled by room temperature water that flows through the grooved channels in the back-plate. Especially, the coolant has been designed to sufficiently remove heat influx up to 4.5MW/m^2 in the divertor region under steady state operation. In addition to the heat removal capacity of the cooling system, the PFCs have been also designed to be compatible for baking temperature of 350℃[2].

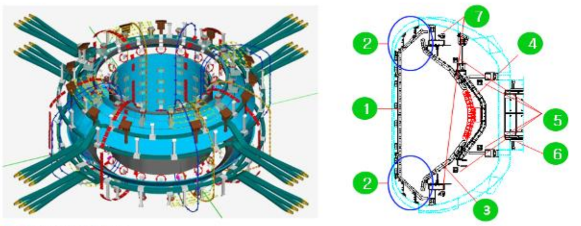

Fig 1. Configuration of the KSTAR PFCs

2.1 Baking & Cooling (B&C) Lines of the PFCs

The B&C lines of the PFCs are divided into two groups. The first group (called as group A) composed of top and bottom B&C lines that contain inboard, central and outboard divertors. Another group (called as group B) includes upper and lower B&C lines that consist of inboard limiter, passive stabilizer (with connection plate, mechanical bridge), NB armor and poloidal limiters. Fig 2 shows a diagram of the B&C lines and the location of the thermo-couples for temperature measurement of the PFC tiles. More than 200 of thermocouple (NiCr-Ni K type) were installed in the graphite tiles at 5mm behind the surface [3]. All the sensors provide a basic tool for the temperature control between every PFCs component through real-time monitoring of the temperature on the tiles and structures.

The B&C lines were welded and tightly tested after the back-plates have been assembled. Prior to start of the assembly of the PFCs, vacuum leak detection test was performed by helium after all the PFCs system have been filled with N2 gas to 15 bar, and after sensitivity of the helium leak detector keeps lower than 5.0 x 10^{-10}

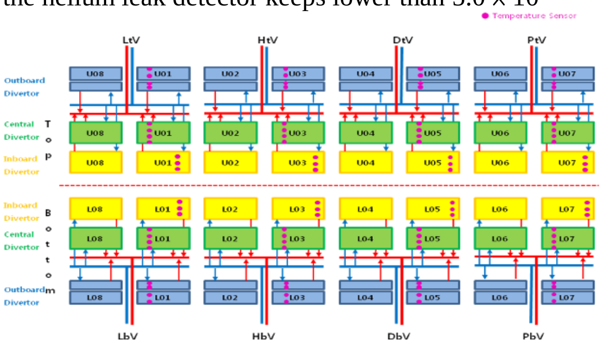

Fig 2 (a). Top and bottom B&C lines(Group A)

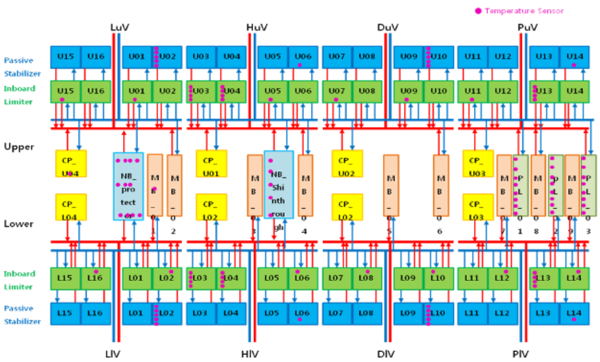

Fig 2 (b). Upper and lower B&C lines(Group B)

Table 1. Flow parameters and tube layout for each PFCs (when PFC is kept at 30℃, 5.3bar)

Flow parameter	**ID**	**CD**	**OD1 OD2**	**IL**	**PS**
Velocity(m/s)	7.0	5.4	8.8	19.3	17.4
Mass flow (per channel) (g/s)	6.9	5.0	8.0 6.2	17.0	8.4
Total mass flow (g/s)	554	554	554	273	536
Pressure dorp(bar)	0.030	0.012	0.032	0.149	0.033
Tube inner diameter(mm)	7.3	7.0	7.0 6.1	13.8	10.2

mbar.l/s in the leak rate. All welding points were detected by helium leak detection on every step of installation. After a section was finally finished in connection, each B&C lines were pressured again by similar process as mentioned earlier. Table 1 shows the flow parameter and tube layout for each PFCs.

2.2 Requirements of the PFCs Baking

Main purpose of the high-temperature baking is removal of several gases such as H_2, H_2O, CO, CO_2 that are detrimental to plasma from the surface of the PFC and VV. The PFCs are to be baked up to 300℃ while the VV maintains at 120℃. The PFCs baking is implemented by flowing hot nitrogen gas with 350℃ of inlet temperature through the tubes which are embedded in the back-plates of the PFCs. The PFC reaches 120℃ for heating rate of 5℃/h and 300℃ for heating rate of 3℃/h, respectively.

2.3 Results of the PFCs Baking

The PFCs were heated by circulating the nitrogen gas in 5 bar of gas pressure through internal holes or external tubes. The surface temperature of the PFCs was increased from the room temperature to 200℃ through more than 6 days of baking operation. The rate of temperature increase was 3~5℃/h which has been determined to minimize mechanical stress on the VV and PFCs structure.

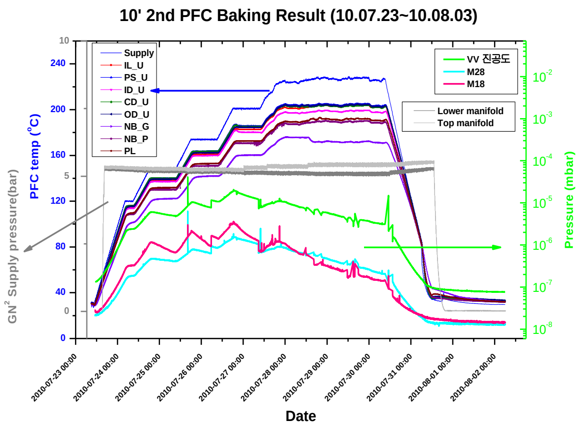

Fig 3. 10' 2nd PFC baking result

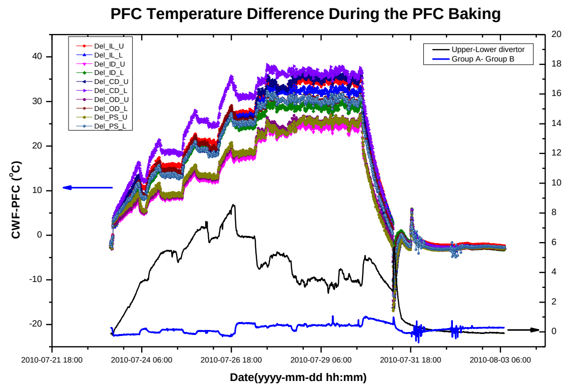

Fig 4. PFC temperature difference during the PFC baking

While the temperature of nitrogen gas supply was increasing, the surface temperature of PFCs was uniformly controlled to keep temperature difference within 50℃ as shown in the Fig 3, and 4. In group A, the mean temperature difference between the upper and lower divertors was lower than 10℃. The average temperature difference was lower than 1℃ between group A and B.

When the supplying pressure of nitrogen gas was raised to 5.0 bar, partial pressure of mass 28 amu (N_2 or CO) was satisfactorily maintained within allowable value. And which result shows no detectable nitrogen leakage from the PFCs B&C lines.

3. Conclusions

According to the past experimental results, high temperature baking (200℃) is quite effective to expedite the removal of water on the graphite PFCs. Consequently, all graphite tile of the PFCs were baked to 200℃ in maximum surface temperature. After PFCs baking, the VV pressure is decreased from 1.35 E-7 to 7.73 E-8 mbar and the partial pressure of mass 18 amu (water) is decreased from 2.5 E-8 to 1.5 E-8 mbar. Moreover, the partial pressure measurements showed that there was no nitrogen leakage in the PFC B&C lines, which satisfactorily meets the most important requirement in the PFCs system.

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