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Design and operation results of nitrogen gas baking system for KSTAR plasma facing components

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HIGHLIGHTS

- Vacuum pressure in a vacuum vessel arrived at 7.24×10^{-8} mbar.
- PFC temperature was reached maximum 250 °C by gas temperature at 300 °C.
- PFC inlet gas temperature was changed 5 °C per hour during rising and falling.
- PFC gas balancing was made temperature difference among them below 8.3 °C.
- System has a pre-cooler and a three-way valve to save operation energy.

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ABSTRACT

A baking system for the Korea Superconducting Tokamak Advanced Research (KSTAR) plasma facing components (PFCs) is designed and operated to achieve vacuum pressure below 5×10^{-7} mbar in vacuum vessel with removing impurities. The purpose of this research is to prevent the fracture of PFC because of thermal stress during baking the PFC, and to accomplish stable operation of the baking system with the minimum life cycle cost. The uniformity of PFC temperature in each sector was investigated, when the supply gas temperature was varied by 5 °C per hour using a heater and the three-way valve at the outlet of a compressor. The alternative of the pipe expansion owing to hot gas and the cage configuration of the three-way valve were also studied. During the fourth campaign of the KSTAR in 2011, nitrogen gas temperature rose up to 300 °C, PFC temperature reached at 250 °C, the temperature difference among PFCs was maintained at below 8.3 °C, and vacuum pressure of up to 7.24×10^{-8} mbar was achieved inside the vacuum vessel.

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1. Introduction

Cleaning and conditioning of the wall are quite important for effective plasma operation [1]. The Korea Superconducting Tokamak Advanced Research (KSTAR) in 2011 was performed a glow discharge cleaning, a vacuum vessel (VV) baking using water at 120 °C, a plasma facing component (PFC) baking using nitrogen gas (GN_2) at 300 °C and a pumping duct baking using heating cable at 110 °C to remove the impurities. The PFC GN_2 baking system was developed to remove impurities such as H_2O, H_2, CO, and CO_2 from the surface and the pole of a graphite tile and to realize a vacuum pressure below 5×10^{-7} mbar inside the VV. The system for baking the PFC up to 300 °C was designed to be stably operated at 400 °C of PFC inlet gas temperature (T3, heater outlet gas temperature) with preventing the mechanical fracturing of the PFC by thermal stress and minimizing the life cycle cost. To prevent their fracturing, the system was studied about an automatic control system in order that the inlet gas temperature can be varied by 5 °C per hour, and the mass flow rate of gas into each sector was balanced by manual valves on inlet piping in each sector. This system which is a semi close loop system consists of an industrial compressor to be operated at maximum 180 °C, a three-way control valve to use compression heat, a pre-cooler to save the operating energy and a cooler to be cooling-off inlet gas of compressor by 90 °C. The system has operating features that the T3 is depended on the PFC outlet gas temperature (T4), the variation of compressor inlet gas temperature (T6) caused the variation of mass flow rate and T3 was varied by adjusting of the three-way valve at below 150 °C and operating of a pre-cooler and heater at above 150 °C in rising and falling stages.

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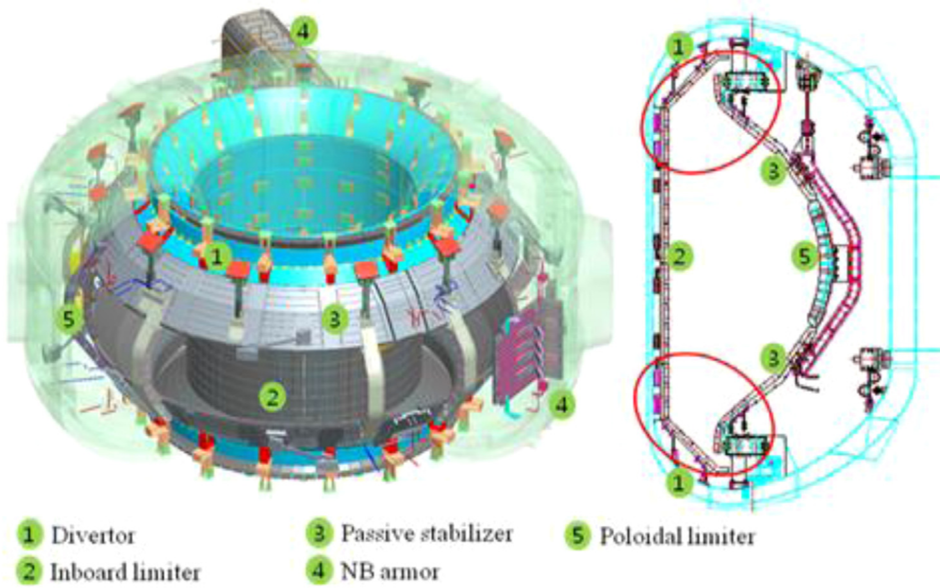

Fig. 1. Components of PFC [3].

Table 1
Requirements [4] and design conditions.

Contents	Requirements	Design
Graphite tile temperature (°C)	300	>300
PFC inlet gas temperature/ΔT (°C)	350/20	400
PFC inlet gas pressure/ΔP (bar)	<10/2	<9.9
Nitrogen gas flow rate (ℓ/s)/(kg/h)	760/14,796	830/15,164
Baking load (MW)	0.082	>0.082
ΔT between PFC (°C)	<20	<20
ΔT in temperature rising and falling the PFC (°C/h)	<30	<30

In this paper, we describe the design features, component specifications, method for flow rate balancing of each sector, and operation results of the PFC GN_2 baking system.

2. PFC description

As shown in Fig. 1, the PFC consists of a divertor that can be divided into inboard, central, and outboard regions; an inboard limiter; a passive stabilizer including a mechanical bridge and supports; neutral beam (NB) protection armor including an NB entrance port protector and NB shine-through; a poloidal limiter [2]. The divertor is designed to achieve effective particle control to maintain high-quality plasma with enough shaping flexibility to accommodate a wide range of plasma operation [3].

A piece of the PFC which is comprised of many graphite tiles and back plates made of copper alloy and STS316LN is bolted a graphite tile and a back plate together. They are attached on the inner surface of the VV by brackets. The back plates have passages to flow baking gas and cooling water. The vacuum pumps for the VV are operated in all stages of the KSTAR campaign; into their passages, baking gas is supplied during the vacuum exhaust stage and cooling water is circulated during the plasma operation stage.

3. Baking system design

3.1. Design conditions

The design requirements of the PFC GN_2 baking system are listed in Table 1 [4], and a schematic of the closed-loop system is shown in Fig. 2. All components except the compressor have a maximum operating temperature of over 400 °C.

The variation rate of gas temperature and the temperature difference among the PFCs should be limited to prevent the PFC from fracturing due to thermal stress. The initial pressure and temperature for operation of the system should be set at 4.5 bar and 25 °C, respectively, in order to maintain the density for design mass flow rate.

The interface pipe except the main pipe and PFC passages are designed to be used as the same passage for baking gas and cooling water. The PFC is baked by GN_2 in the vacuum exhaust stage and cooled by de-ionized (DI) water in the plasma operation stage. Therefore, after baking operation, the gas is fully removed from the interface pipe and PFC passages; DI water is filled in these spaces in low-vacuum conditions.

3.2. Components design

The PFC GN_2 baking system consists of a compressor, an electric heater, a pre-cooler (gas vs. gas), a cooler (gas vs. water), and a vacuum pump, three-way valve, as shown in Fig. 2. To operate the compressor stably, T6 should be cooled down to 90 °C by the cooler, following which its discharge temperature would be 150 °C.

The heater should have a large capacity in order to increase the T3 from 150 °C to 400 °C, because the maximum compressor outlet gas temperature is 150 °C. However, it was designed with the capacity to increase the gas temperature by a differential of 50 °C, as shown in Table 2, because this system has the pre-cooler that can increase the heater inlet gas temperature (T2) when the T4 exceeds 150 °C.

The purpose of the vacuum pump is to maintain a pressure of under 0.013 bar in the circuit after evacuating the GN_2 or moisture inside the baking circuit. If the gas is not evacuated after the gas baking operation, gas pockets might interrupt the flow of DI water and circulate lesser than the design flow rate.

As shown in Fig. 2, the gas temperature of a right-angled port (GTRP) and the recycle cooler outlet gas temperature in the three-way valve is varied at 90–150 °C and is steady at 30 °C, respectively. To minimize the fluctuation of mixed gas temperature (T1), the valve should be satisfied with the following condition, the compressor outlet flow rate and the recycle cooler outlet one are in

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