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Improvement of initial vacuum condition along 2008–2010 KSTAR campaign by vessel baking

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ABSTRACT

Korea Superconducting Tokamak Advanced Research (KSTAR) is upgraded for its KSTAR 3rd campaign for new target mission to produce the D-shaped plasma with a target plasma current of 500 kA and/or pulse length of 5 s. New Plasma Facing Components (PFCs) are installed which leads to the increase of the surface area of the vessel by a factor of about 5. The vacuum conditioning such as the vessel baking has been performed in order to remove various kinds of impurities including H_2O, carbon and oxygen for the plasma. The total outgassing rate in the KSTAR 1st campaign was measured as 1.5×10^{-4} mbar ℓ s^{-1} which is increased by a factor of 3 (6.49×10^{-4} mbar ℓ s^{-1}) in the KSTAR 3rd campaign. Nevertheless, the outgassing rates per unit area have been decreased from 9.31×10^{-5} mbar ℓ m^{-2} s^{-1} to 1.22×10^{-5} mbar ℓ m^{-2} s^{-1} due to the upgrade of baking system and series of baking operation.

1. Introduction

To maintain a good initial vacuum condition for a tokamak experiment, wall conditioning procedures are essential to obtain high-quality vacuum condition. Therefore, a few wall conditioning techniques have been simultaneously or sequentially employed in order to remove various kinds of detrimental impurities including H_2O, carbon and oxygen. Among the various wall condition techniques, typical initial wall conditioning procedures after vacuum opening to the atmosphere are the baking and Glow Discharge Cleaning (GDC) methods.

In conventional tokamaks, the baking of the vacuum vessel and components contained therein is immediately performed for several days according to the baking temperature after base pressure reaches less than $\sim 10^{-7}$ mbar [2,4]: a vacuum pressure of 1.9×10^{-7} mbar was obtained after approximately 330 h at 100 °C baking operation in HL-2A tokamak system [2]. LHD was baked at 100 °C [3]. For graphite walls in the vacuum chamber, the walls were baked up to nearly 200–300 °C for about 10 days before the plasma discharges in HT-7 [4].

Carbon based materials such as graphite and Carbon Fiber Composites (CFCs) are commonly used in fusion devices as a tile material for Plasma Facing Components (PFCs), owing to the excellent thermal properties of the material. However, their outgassing conditions: outgassing species are hydrogen (H_2), water (H_2O), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), etc. with a typical rate 1.0×10^{-9} mbar ℓ m^{-2} s^{-1} [5].

In this paper, we described the improvement of initial vacuum condition by baking along 2008–2010 KSTAR campaigns after the installation/upgrade of the baking system. In Section 2, upgraded components of baking system and baking operation through the campaigns will be discussed. In Section 3, we will describe the results of baking operation. And a conclusion will be given.

2. Baking system upgrade and baking operation

2.1. Baking system upgrade

The base pressure of the vacuum vessel depends on the total volume and the condition of the inner surface of the vessel, and the effective pumping speed. The main pumping system is composed of eight TMPs and two cryopumps. The pumping capacities of each TMP and cryo-pump are 2800 ℓ s^{-1} and 10,000 ℓ s^{-1}, respectively.

The VPS was designed to have a base pressure below 5.0×10^{-7} mbar with full pumping capability. After the successful self-commissioning of the VPS in August 2007, the Vacuum Pumping System (VPS) has operated without any problems throughout the past two years.

To archive the goal pressure, the outgassing rates from surfaces of walls and PFCs have to be identified. The KSTAR vacuum vessel

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Fig. 1. Step-by-step installation of Plasma Facing Components from 2008 to 2010.

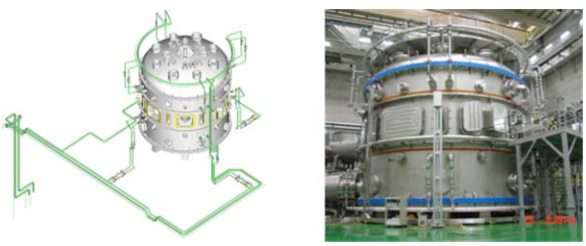

Fig. 2. The piping diagram for the water baking system.

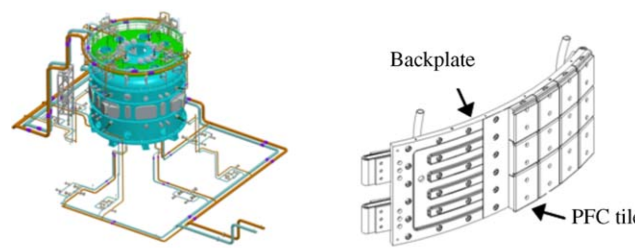

Fig. 4. The piping diagram of the GN_2 line and tiles of the inboard limiter.

made of stainless steel 316LN with inner volume of 100 m^3 and with inside surface area of 80 m^2. The vacuum vessel is equipped with a pumping duct with inner volume of 14 m^3 and surface area of 38 m^2, respectively. In 2010, the surface area of PFCs increased from 1.54 m^2 (KSTAR 1st campaign) to 54 m^2 (KSTAR 3rd campaign) as shown in Fig. 1.

The vacuum vessel has a double-walled configuration for cooling water flow between the walls. To bake the vacuum vessel, De-Ionized (DI) water is heated to 130 °C and circulates through the cooling channel. As shown in Fig. 2, toroidal rings, poloidal ribs, and port stubs were installed to supply the DI water. Eight vacuum ports are utilized for inlets and outlets of the DI water with a quadrant unit (every 90° space) along the toroidal rings on the vacuum vessel upper and lower parts. There are 8 channels in the vacuum vessel. Each channel contains one ton of water. The length of each passage is about 40 m [6].

Before the KSTAR 2nd campaign, a jacketed heater system made of 1 mm diameter nichrome wire was installed for baking of the pumping duct (see Fig. 3). The heater system mainly comprises 16 pieces of heaters, 6 units of control system, and 19 units of temperature sensors. The jacked heater was designed to be able to raise the temperature up to 200 °C.

In the KSTAR 3rd campaign, most of in-vessel component for 20-s operation such as inboard limiter, divertor, passive stabilizer, in-vessel control coils (IVCC), in-vessel cryo-pump (IVCP), and various kinds of diagnostic systems have been newly installed in the vacuum vessel. Consequently, the effective surface area in the vacuum vessel drastically increased from 11 m^2 to 54 m^2. Besides the baking system for the vacuum vessel, another baking system by using a hot nitrogen gas supply system, which was originally designed to heat the PFC tiles to 350 °C [7], was installed on the backside of PFCs. The nitrogen supply system supplies the hot nitrogen gas to every 16 independent channels. During baking period, almost 200 temperature sensors provide an essential tool for the monitoring of temperature behavior of the in-vessel component. The piping configuration to supply the hot nitrogen gas and tiles of the inboard limiter is shown in Fig. 4.

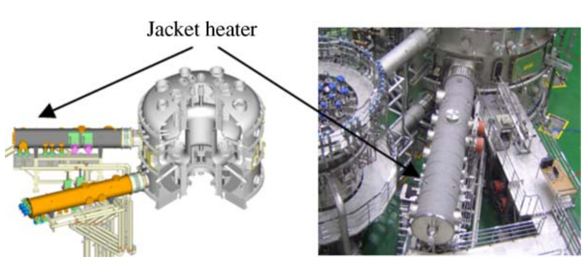

Fig. 3. Jacket heaters system for the pumping duct.

2.2. Baking operation

As mentioned earlier, the main purpose of high temperature baking is to clean the in-wall surface of the vacuum vessel, PFCs and the pumping duct surface to reduce the out-gassing rate as low as possible, and to remove the high Z impurities in order to produce high quality plasma. Hence, three baking methods have been employed to clean all the surface of the KSTAR vacuum vessel. Several key parameters of the baking-related conditions are summarized in Table 1.

During the KSTAR 1st campaign, the vacuum vessel was baked up to 100 °C by hot pressurized water and simultaneously H_2 or helium GDCs were combined (120 h) as shown in Fig. 5. As the water temperature increases, the pressure in the vacuum vessel increases due to the increase of outgassing. In the KSTAR 1st campaign, a

Table 1
Major parameters and baking method of each vacuum system.

Item	Vacuum vessel	Pumping duct	PFCs 1st/2nd/3rd
Volume (m^3)	110	14	
Surface area (m^2)	80	38	1.54/11/54
Baking method	Hot water	Jacket heater	Hot N_2 gas
Temperature (°C)	Max.130	Max.200	Max.350
Material	Stainless steel 316LN	Stainless steel 304	Graphite