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Development of KSTAR in-vessel components and heating systems

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ABSTRACT

In-vessel components of the Korea Superconducting Tokamak Advanced Research (KSTAR) were developed for 2010 campaign to provide a crucial circumstance for achieving the strongly shaped and diverted plasma. Moreover, the in-vessel components such as limiter, divertor, passive stabilizer, in-vessel control coil (IVCC) system demonstrated good performances satisfying the original design concepts. In addition to the plasma facing components and the IVCC, in-vessel cryo-pump (IVCP) system was also installed to leverage divertor operation. Besides the in-vessel components, there have been substantial progresses in development of the heating and current drive system. The KSTAR heating and current drive system includes all kinds of the major heating systems such as neutral beam injection (NBI), ion cyclotron range of frequency (ICRF), electron cyclotron resonance heating and current drive (ECH and ECCD), lower hybrid current drive (LHCD) systems. As an initial stage for full equipment of the heating systems to total power of 26 MW, several key systems such as 1st NBI (called NBI-1), ICRF, and ECH-assisted startup system successfully demonstrated their excellent feasibilities in the design and performances for dedication to the 2010 campaign.

1. Introduction

After completion in the construction by middle of 2007, the Korea Superconducting Tokamak Advanced Research (KSTAR) succeeded in production of the first plasma in 2008, and also achieved fruitful results in 2009 campaign [1]. However, the absence of a few important systems that have been omitted in the construction phase imposed a major limit on the KSTAR operations in past 2 years. As a result, progress of the KSTAR upgrade became most urgent concerns for the meaningful KSTAR operations in the future.

The in-vessel components system such as limiters, divertors, passive plates, active control coils, and divertor pumping system is one of the most important systems to be upgraded in the KSTAR device. Especially, the 2010 KSTAR campaign mainly aims to achieve strongly elongated and diverted plasma. This goal requests that all of the in-vessel components for 20-s operation should provide an essential environment in the vacuum vessel. Consequently, the requirements brought the KSTAR to equip the in-vessel components by end of May 2010, which was followed by subsequent vacuum operation of the KSTAR from start of June 2010. Although both electron cyclotron heating (ECH)-assisted startup system and ion cyclotron range of frequency (ICRF) system have been successfully operated with remarkable performances in 2008 and 2009, almost heating and current drive (H&CD) systems are still under development. Because insufficiency of several key H&CD devices such as neutral beam injection (NBI) system, electron cyclotron current drive (ECCD) system, and lower hybrid current drive system (LHCD) may decisively impact not only on the 2010 campaign but also on the forthcoming steady-state operation experiments, it is impossible to overestimate the importance of the H&CD system development.

This paper will generally summarize development status of the in-vessel components and H&CD system, as well as report on outlined descriptions for the configuration, functions, and tested performances of each system mentioned earlier.

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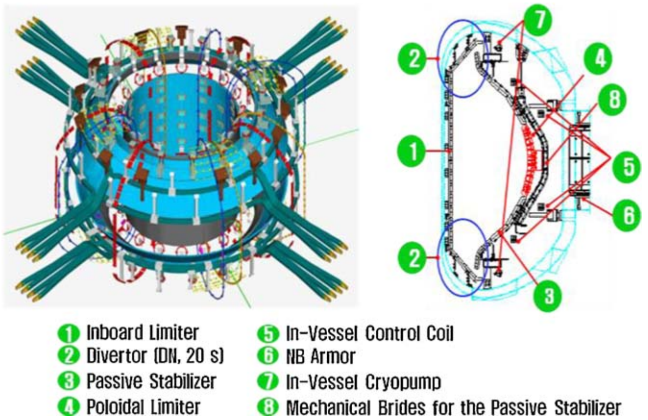

Fig. 1. Configuration of KSTAR in-vessel components.

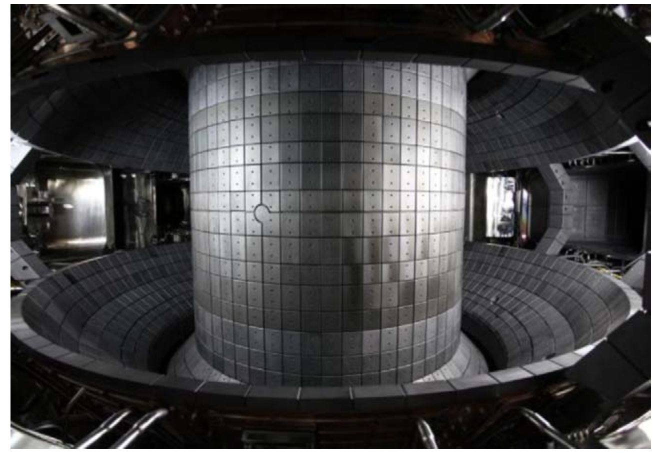

Fig. 2. Inside of vacuum vessel in which PFCs are installed.

2. In-vessel components

2.1. Plasma facing component

As shown in Fig. 1, the plasma facing component (PFC) consists of inboard limiter, divertor that can be divided into inboard, central, and outboard regions, passive stabilizer, poloidal limiter, and NB protection armor. Heat-sink plate of the inboard limiter has a toroidally continuous cylinder-shape, which are made of stainless steel (SS316LN) with internal cooling channels for active water cooling and baking. The plate is installed on the straight section of the vacuum vessel, and is covered by graphite tiles that are simply mounted on the plate by bolts. While 12 sub-segments among 16 sub-segments of the inboard limiter are covered by graphite tiles and the remaining 4 sub-segments will be covered with carbon fiber composite (CFC) tiles, on which energetic neutral beam strikes and strong heat influx take place.

The divertor system consists of inboard, central and outboard parts. Each part contains 8 heat-sink plates that locate in upper and lower side of the vacuum vessel with up-down symmetry for double-null (DN) operation. Entire area of the heat-sink plates is covered with CFC tiles by bolts to withstand high temperature (maximum 1200 °C) at a striking point for the case of maximum heat influx of 4.3 MW/m^2. Since the divertor concept with bolted CFC tiles is not sufficient for heat removal from the tiles in long-pulsed operation (300 s), the divertor should be fully upgraded again in 2015 (or 2016) with a new concept of heat removal mechanism, and tile materials.

The passive stabilizer will play roles both on plasma position control and on MHD instabilities suppression through various combinations with active control coils. Two toroidal ring-shaped copper plates made of CuCrZr alloy have up-down symmetry. The upper plate is supported by 12 vertical supports and by four horizontal supports, while the lower plate is supported by 9 mechanical bridges that are connected to the upper plate. Each plate is electrically segmented into four quadrants, and a quadrant is electrically connected to an adjacent quadrant by "gap resistors" to adjust total resistance of the passive plate in toroidal direction. The poloidal limiter comprises three D-shaped strings to protect launchers of the ICRF and LHCD. Because the KSTAR NBI system is composed of two beam lines, the NB protection armor system also comprises two sets of actively cooled CFC tiles.

After termination of the final design, fabrication and installation of the PFC system has been launched in middle of 2009, and all the sub-components were installed in the vacuum vessel in middle of May 2010. Fig. 2 shows inside of vacuum vessel with newly installed PFC system. Although several components that are to be covered with CFC tiles in the original design, all of the PFCs were covered with graphite for 2010 campaign owing to relatively low heat flux and short pulsed operation. Especially, the divertor tiles will be replaced as CFC in 2012. Prior to start of 2010 campaign, the PFC system has been baked to 200 °C, and will be verified whether the PFC system is compatible enough for designed baking temperature (350 °C) in 2011. The experimental results of the PFC in 2010 showed that the passively cooled PFC worked very well and provided an essential environment for strongly shaped and diverted plasma. However, the supporting structures and graphite tiles of lower passive stabilizer were substantially damaged owing to destruction of insulation bushes for the bolting structures between mechanical bridge and lower passive plate. The broken bushes that were made of polyimide plastic will be replaced to stainless steel washers on which an insulation layer is specially coated to withstand the baking temperature.

2.2. In-vessel control coil (IVCC)

The IVCC system was developed to take advantages of active control for the plasma position, field error correction (FEC), and that for resistive wall mode (RWM) [2,3]. More recently, the IVCC is expected to be effectively utilized in suppression of edge localized mode (ELM). This important system adopted a unique concept of segmented coil system to have 16 segments and their support structures [4]. Each segment contains eight water-cooled normal coppers that are partially connected to an adjacent segment in series to form 4 circular coils for position control as shown in Fig. 3, while remained copper conductors are connected to a vertically

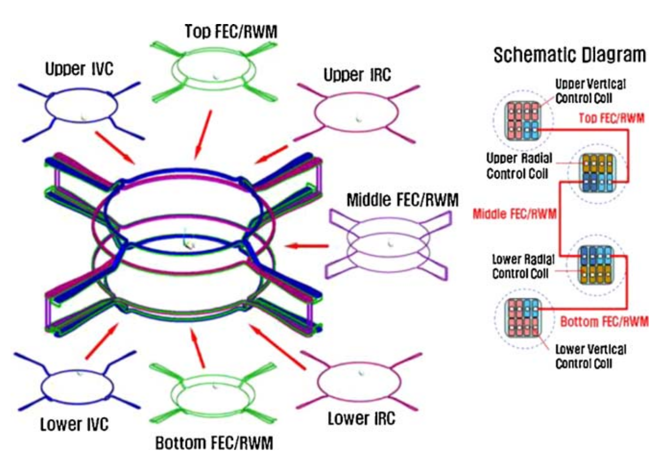

Fig. 3. Electrical connection scheme of the IVCC.