KSTAR Assembly

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Abstract. Since all of the sixteen toroidal field (TF) magnets were completely assembled in February 2006, the assembly of the KSTAR is being actively progressed to meet the assembly finish by the middle of 2007. According to the assembly plan, all the SC magnets and most of the in-cryostat components such as the buslines, helium piping system, thermal shields, and various sensor cables will be installed in the cryostat within 2006. Moreover, we are preparing the integrated commissioning plan in parallel with rigorous assembly works. In this paper we present an overview of the KSTAR assembly progress report up to October 2006, and the remaining works including general commissioning plan.

1. Introduction

The Korea Superconducting Tokamak Advanced Research (KSTAR) is an advanced superconducting tokamak designed to establish a scientific and technological basis for an attractive fusion reactor [1, 2]. The KSTAR project has been in progress since 1995, and now most of the major structures of the KSTAR have been designed and manufactured. Assembly activities were started to integrate the KSTAR tokamak in 2004. Although the KSTAR assembly mainly covers the assembly of the KSTAR major structures such as the vacuum vessel (VV), cryostat (CR), support structures, superconducting (SC) magnets, thermal shields, the assembly activity regulates the integration planning, space allocation, quality assurance for the entire tokamak system. The assembly work scope also includes the several important sub-assemblies of the major structures including the central solenoid (CS). Moreover, the KSTAR assembly also carried out assembly-related activities such as design and fabrication of the jigs & tools system and establishment of the survey & alignment network system.

At the beginning of the 2004, the site assembly of the KSTAR started with the installation of the CR base and it progressed well without any serious trouble up to the end of September 2006. Consequently, the KSTAR assembly is expected to be finished by August 2007, and we are now preparing the integrated commissioning, which will start at the moment of assembly finish time. In this paper, a general overview of the history, strategies, configurations, remaining works, and near future schedule of the KSTAR assembly & commissioning plan will be described in detail.

2. Key Features and Strategy of the KSTAR Assembly

2.1 Coordinate System of the KSTAR Assembly

The coordinate system of the KSTAR assembly comprises two sets of "coordinate data" according to the assembly progress. The 1st set of the "coordinate data" is established from a comprehensive survey and fitting on the geometry of the CR base, and this set is called a "pit data". The pit data provides all the references for the site assembly until the TF magnet system is assembled. The 2nd set (called "tokamak data") is produced after assembly completion of the TF magnet to provide a reference set for the SC magnets. Because the SC magnets thermally shrink at the cryogenic temperatures as illustrated in figure 1 [3], the mid-plane in the tokamak data is offset from the pit data by 5 mm to make the two sets coincide in operation. That is, the mid-plane in the tokamak data is 4,205 mm from zero level instead of the 4,200 mm that comes from the pit data. The tokamak data also provides the basis for the TF magnet to be assembled at 7 mm outward in radial direction from the designed position at cryogenic temperature.

2.2 Assembly of the VV and TF magnets

The unique feature in the KSTAR assembly is assembly of the VV and TF magnets as shown in figure 2. The 337.5° sector of the VV and the VVTS are completed through site welding. After final installation of the VV and VVTS, each of the sixteen TF magnets passes through the 22.5° gap of the VV. Next, each TF magnet rotates around the VV to the final position. However, a tool system is needed for the TF magnet to be assembled owing to the narrow clearance between VVTS and TF magnets. As a result, the remaining 22.5° sector of the VV (called VV sector 3) and VVTS should be assembled inside of the TF magnet system. The configuration means that the VV sector 3 to be composed of 24 pieces, which are welded from inside of the VV. Because the VV 337.5° sector is formed through site welding of the 180° and 157.5° sectors of the VV, the site weld should be controlled as accurately as possible for the assembly of the TF magnets and for the final welding of the VV sector 3 components.

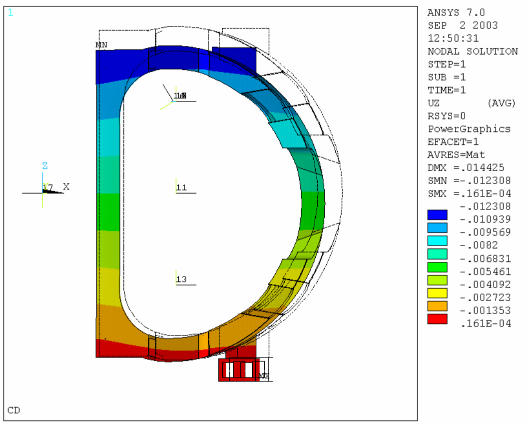

FIG. 1 Analysis result of the thermal shrinkage of the TF magnet

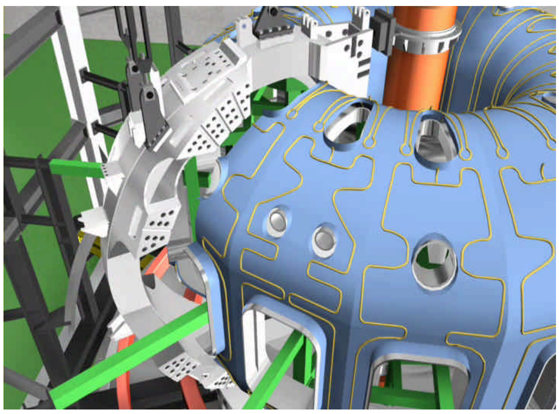

FIG. 2 Schematic drawing - insertion of a TF magnet into torus of the vacuum vessel

2.3 Assembly of the Port Modules

The KSTAR VV has 72 ports including baking & cooling ports of the VV. All of the ports have the bellows to accommodate thermal expansion of the VV during baking period. Because the KSTAR device will be enclosed by a cryostat, every VV port has to penetrate the cryostat to access the vacuum vessel from the outside. As illustrated in the figure 3, the port & bellows module should be inserted into the port openings and meet with the port stub on the VV surface. This configuration requires that the VV port stub and port opening on the cryostat should coincide as accurate as possible to assemble the port module. Moreover, there are pre-installed port thermal shields along the path of the port penetration. This configuration means that the port is to be installed by carefully moving it through a tunnel in the port thermal shield. Therefore, the tolerance in the fabrication & assembly of the VV, CR, and port thermal shield should be strictly controlled and monitored during the assembly period.

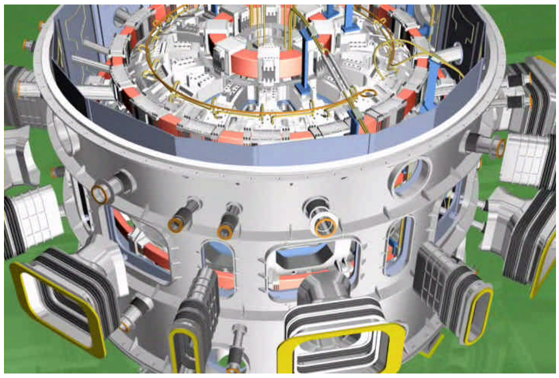

FIG. 3 Schematic drawing of the port assembly

2.4 Sub-assembly of the CS Coil

The KSTAR central solenoid (CS) module is composed of 8 Nb_3Sn superconducting coils and structures for robustly holding the coils during operation. Figure 4 shows the detailed configuration of the CS module. The difficulties in the sub-assembly of the CS coils mostly stem from the configuration of the coil leads that comes out from the inside of the coil, which makes a complicated geometry and a small space to work inside of the coil stack. Another feature is the pre-loading on the CS coils. Because the CS coils are sustained by compressive force and frictions between each coil, applying a pre-load during the room temperature assembly is very important. Electromagnetic load calculations on the basis of the operation scenario show that several hundred tons are needed for the CS module to be safely sustained from repulsive & lateral force [4]. According to the requirements, the assembly plan includes a special jig system for stacking the complicated CS coils and pre-loading on the CS coils.

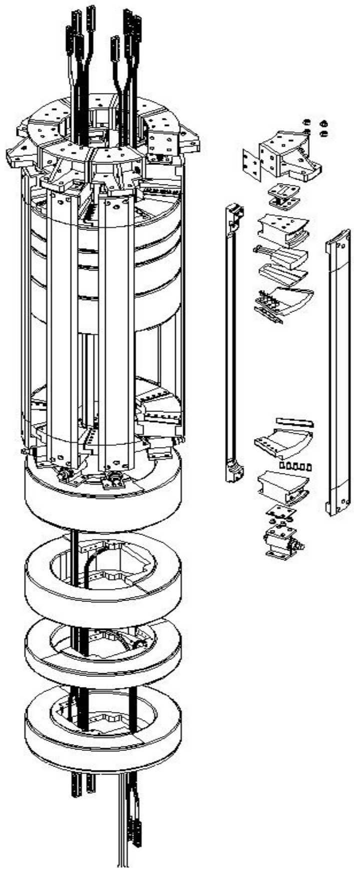

FIG. 4 Detailed configuration of the CS module

3. Progress in the Site Assembly

3.1 Assembly of the Cryostat Base, Gravity Support, and VV

As detailed assembly procedures and results were described in an earlier conference [5], the cryostat base, gravity support, and 337.5° sector of the VV were put together in the assembly hall by September 2004. Figure 5 shows the assembled cryostat base and gravity support, and figure 6 shows the 337.5° sector of the VV after final on-site welding.

3.2 Vacuum Vessel Thermal Shield (VVTS)

The silver plated VVTS panels were installed in the assembly hall after completion of the 337.5° sector of the VV as described in detail in ref. [6]. Completion of the VVTS installation on the VV made a 337.5° sector of VV & VVTS, which was transported and installed on the tokamak pit in February 2006. Figure 7 shows the 337.5° sector of VV & VVTS after the final installation.

3.3 Assembly of the TF Magnet

Since the 1st TF magnet was delivered to the site in February 2005, all sixteen TF coils were assembled with help of the main assembly jig system in March 2006 by the same procedure. The details were described in ref. [5]. Figure 8 shows that the TF magnet system after completion in the final assembly.

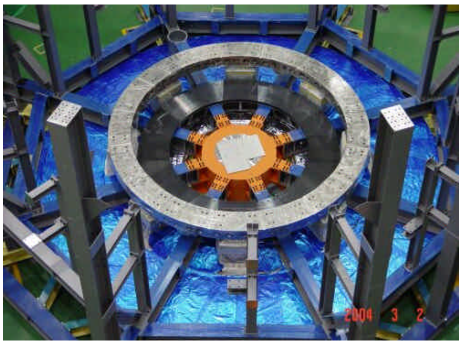

FIG. 5 Cryostat base & gravity support after assembly finish

FIG. 6 337.5° sector of VV after site welding

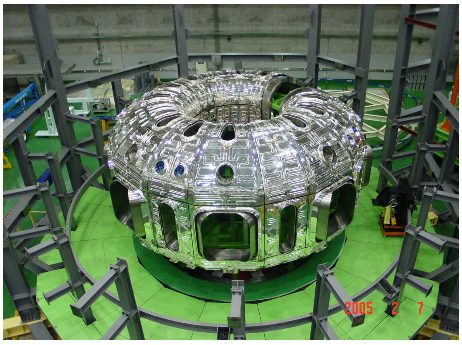

FIG. 7 337.5° sector of VV & VVTS after completion of the assembly

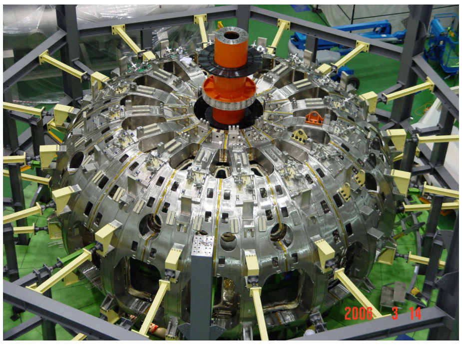

FIG. 8 TF Magnet after completion of the assembly

Figure 9 (a) shows the summarized assembly tolerances in terms of radial, vertical, and toroidal shifts from the designed position. The x, y, and z direction represent the toroidal, radial, and vertical direction of the tokamak geometry, respectively. Figure 9 (b) shows the rotations of each TF magnet on the three axes where one degree corresponds to 0.5 mm at outmost points. Most of the assembly tolerances of the TF magnet system meet the requirement (within ± 1mm) although a few slightly exceed the requirement.

3.4 Assembly of the VV and VVTS Sector 3

The final assembly of the VVTS sector 3 followed the assembly completion of the TF magnets. Because the outside of the VVTS was entirely surrounded with the TF magnets, all components of the VVTS sector 3 were assembled from the inside of the VV on the neighboring VVTS which was already installed on the VV. Especially, the inboard side of the VVTS needs a special connections of the cooling tubes between each poloidal segment because access to the tubes from the outside of the VVTS panel is impossible. To solve this problem, the inboard side of the VVTS sector 3 had small windows which have been finally closed after connection of the cooling tubes by on-site welding. After the VVTS sector 3 had been assembled, all of the VV sector 3 components were welded through GTAW from inside of the VV. Because access to the outer shell of the VVTS sector 3 is impossible if the inner shell is welded, all of the welding seams of the outer shell have been tested for the vacuum leaks using various kinds of small chambers that were temporally attached along the seam lines. The last quadrant of the VV that includes sector 3 was also tested for the vacuum leaks after welding of the inner shell to finally check the leak point on the welding seam of the inner shell. As a result, there is no vacuum leak larger than 5×10^{-10} mbar·l/s and the VV has been satisfactorily closed.

3.5 Assembly of the PF & CS coils

During the on-site welding of the VV sector 3, most of the PF coils were assembled outside of the TF magnet. Figure 10 shows the assembled PF coil system except upper smallest coil

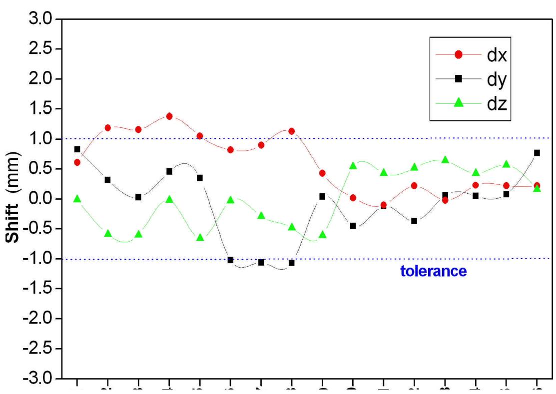

FIG. 9 (a) Assembly tolerance of TF magnet in parallel shift

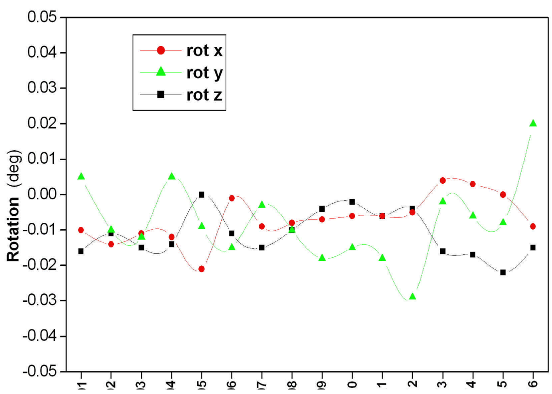

FIG. 9 (b) Assembly tolerance of TF magnet in rotation (called the PF5U coil). The PF6L and PF7L coils have been pre-installed before the VV was placed on the Tokamak pit. Those coils were lifted by eight hydraulic jacks from the bottom of the cryostat base. The PF7U and PF6U coils were lifted by overhead crane and aligned. The PF5L coil has been lifted from bottom of the KSTAR building, and has been passed through the central hole of the cryostat base as shown in Figure 11. The PF5U coil will be assembled after final assembly of the central solenoid (CS) coils. All of the assembled PF coils were aligned within ±1 mm tolerances.

In parallel with assembly of the PF coils, the eight CS coils were sub-assembled in the assembly hall from July to September 2006. Each CS coil was bonded with a half G-10 ring plate on the top (or bottom) surface of the coil to form a complete ring when two adjacent coils are stacked. With this configuration, the G-10 ring plates can provide a partly supporting structure against the rotational and lateral forces between two neighboring coils. The coil structures such as inner shell, outer shell, top & bottom blocks were assembled after the CS coils were stacked through similar procedure that described above. The sub-assembly finish was preceded by attachment of heating pads on the surface of inner & outer shell to apply a pre-load as described earlier. In the pre-loading on the CS coils, a few sensors on the surface of the shells monitored temperature and strain of the shells as shown in (a) and (b) of figure 12. After the shells were heated to more than 140 °C, wedge-shaped spacers were inserted to fill gap between buffers and blocks that connected structures for the inner and outer shell. Cool-down of the shell to room temperature could apply a pre-load due to the thermal shrinkage of the shells, and interpretation of the strain from the (b) of figure 12 showed that the finally applied pre-load was more than 800 tons. The sub-assembly of the CS coils has been completed by middle of September 2006, and is now waiting for final assembly on the TF magnet. Figure 13 shows the CS coils after sub-assembly.

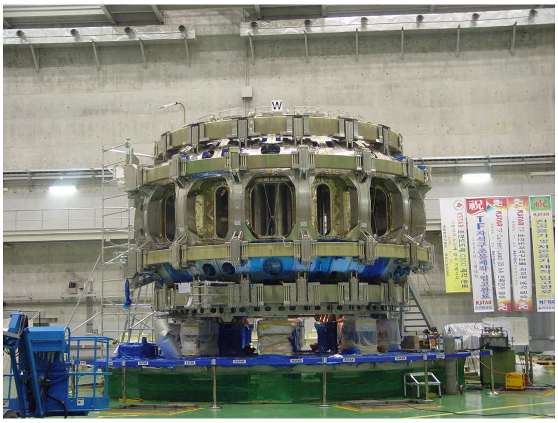

FIG. 10 PF6 and PF7 coils after assembly completion

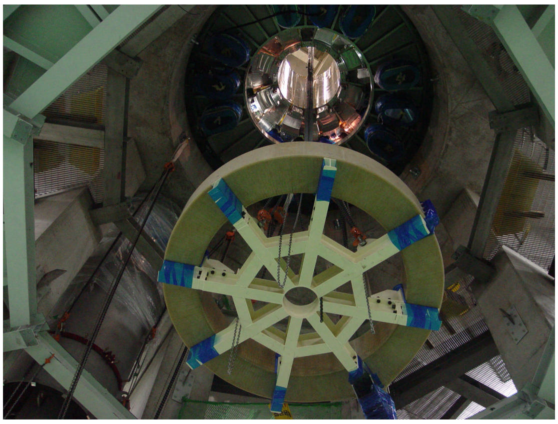

FIG. 11 Lower PF5 coil under lifting from the bottom of KSTAR building

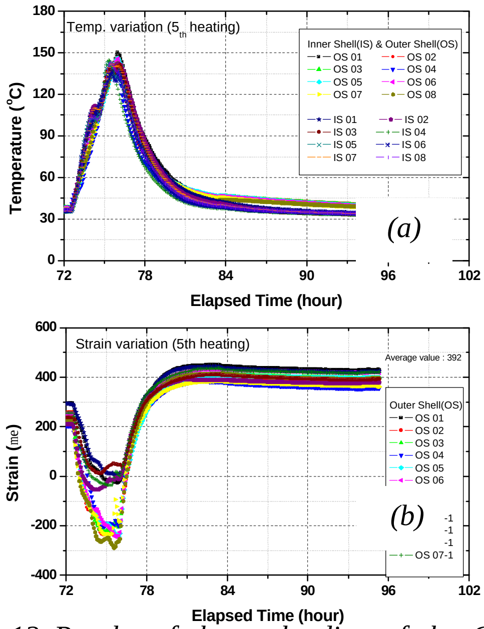

FIG. 12 Results of the preloading of the CS (a) temperature (b) strain

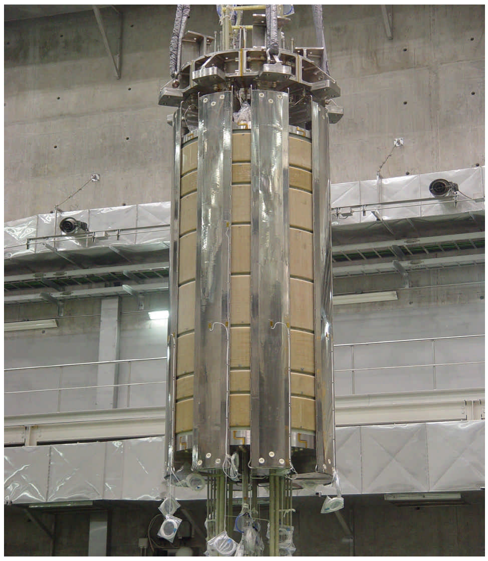

FIG. 13 CS coil after sub-assembly completion

4. Integrated Commissioning

According to the KSTAR construction is on scheduled, we are now preparing for the integrated commissioning of the KSTAR. The commissioning is preceded by individual sub-system tests including vacuum leak tests, electrical insulation tests, SC magnet power supplies tests with dummy loads, helium refrigeration system tests, heating and diagnostic device, and local and central control system. The integrated commissioning will be performed in accordance with the following procedure:

(i) vacuum pressure achievement to start cool-down of the cold mass, (ii) cool-down the cold mass and SC magnets, (iii) checking whether they are at operating temperature and monitoring the transition of the SC magnet into superconducting, (iv) connection of the SC magnets with power supplies and current excitation test up to the defined current level to make the 1st plasma breakdown, (v) performance test of ECH and basic diagnostics, (vi) control systems communication test, (vii) performance test of the safety system and interlocks, (viii) and finally the first plasma production is made to complete all the integrated commissioning activities. The target goal of the integrated commissioning is as follows:

- Vacuum pressure in VV : less than 5.0E-7 mbar
- Vacuum pressure in CR : less than 1.0E-4 mbar
- SC magnet operating temperature : < 5 K
- Thermal Shield operating temperature : 80 K
- Toroidal flux density at plasma center (B_0) : 1.5 T
- Initiation of the 1st Plasma : ECH-assisted ohmic discharge (Ip : 100 kA, 100 msec)

5. Summary

The KSTAR assembly has been progressed well since the start of 2004. As shown in figure 14, most of the major structures have been successfully assembled on schedule. The TF magnets were also assembled with almost meeting the assembly requirements. Five PF coils were assembled on the TF structure by end of August 2006. The CS coils are now waiting for installation on the TF structure through the successful sub-assembly.

After final installation of the PF5U coil and in-cryostat components, the CR cylinder will be assembled in December 2006. Assembly completion of the CR is followed by the site welding of the 60 VV ports on the VV and CR. The in-vessel components including magnetic diagnostics and the inboard limiter for the 1st plasma are now being installed as shown in figure 15. The KSTAR staff is preparing for the integrated commissioning and plan of achieving 1st plasma in accordance with the KSTAR assembly schedule.

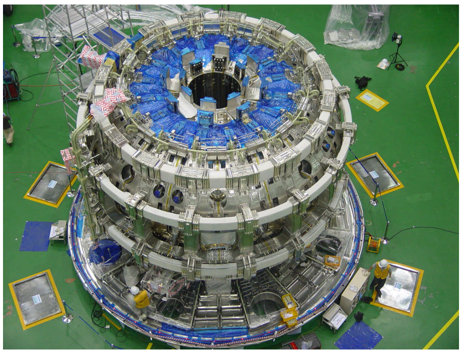

FIG. 14 Status of the KSTAR assembly hall

FIG. 15 Status of in-vessel component installation

Acknowledgement

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