Available online at www.sciencedirect.com
ScienceDirect
Fusion Engineering and Design 81 (2006) 2315–2324
Fusion Engineering and Design
www.elsevier.com/locate/fusengdes

Status of the KSTAR tokamak construction

J.S. Bak *, H.L. Yang, Y.K. Oh, Y.M. Park, K.R. Park, C.H. Choi, W.C. Kim, J.W. Sa, H.K. Kim, G.S. Lee,

the KSTAR Team

National Fusion Research Center (NFRC), 52 Yeoeun-dong, Yusung-ku, Daejeon 305-333, Republic of Korea

Available online 24 August 2006

Abstract

The KSTAR is a superconducting tokamak under construction at the National Fusion Research Center (NFRC) in Daejeon, Korea. The project mission aims at a steady-state operation and advanced tokamak physics. At present, the project is in the peak of fabrication and assembly phase. The fabrication of the major tokamak structures such as vacuum vessel, cryostat, port system, thermal shields, and gravity support, has been completed. The manufacture and testing of the 30 superconducting magnets are rigorously progressing. As of September 2005, 16 toroidal field (TF) coils and four large poloidal field coils have been completed. To verify the operational feasibility of the KSTAR coils, cool-down and current charging tests of a real sized prototype TF coil and a pair of central solenoid (CS) model coil have been carried out. The assembly of the device has begun in the beginning of 2004. Now, the vacuum vessel body, thermal shields and 11 toroidal field magnets were assembled on the tokamak position. Assembly finish is scheduled for August 2007. This paper describes the manufacture and assembly progress of the KSTAR tokamak.

Keywords: KSTAR; Tokamak; Superconducting magnet; Vacuum structure

1. Introduction

After the meticulous engineering design for the KSTAR subsystems, the device is in the peak phase of fabrication and installation with assembly finish milestone by August 2007. As of September 2005, the progress of the KSTAR construction reaches 85% of completion. The fabrication of vacuum vessel, VVTS (vacuum vessel thermal shield), cryostat, welded bellows and supporting structures has been completed. Two large sectors (180°, 157.5°) of the vacuum vessel were delivered to the site in June 2004 and welded with each other at the site to form a 337.5° sector by August 2004. At present, the vacuum vessel torus with thermal shields of fish-scale concept has been installed on position.

The significant progresses on the fabrication and test of toroidal field (TF) and poloidal field (PF) super-

* Corresponding author. Tel.: +82 42 870 1700; fax: +82 42 870 1709.
E-mail address: jsbak@kbsi.re.kr (J.S. Bak).

0920-3796/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.fusengdes.2006.07.014

conducting magnets, have been achieved. Especially, the manufacturing process has been much improved through the rigorous quality control program. Until now, 17 TF coils are heat treated, and all 16 TF coils are encased in structure. Four large PF coils are ready for installation on site, and four central solenoid (CS) coils are in the process of heat treatment. To verify the design and manufacturing engineering and to ensure reliable operation, a real sized prototype TF coil and a pair of CS model coil have been fabricated and tested at the NFRC superconducting magnet test facility. The fabrication of TF coil structure is well progressing on the basis of the experiences obtained from the prototype TF coil structure fabrication. Doosan Heavy Industries & Construction Company has been manufacturing the TF coil structure since March 2004. Up to now eleven TF magnets were delivered to KSTAR site.

According to the great progress in fabrication and delivery of the key components of the KSTAR, the site assembly tasks were started at the beginning of 2004. Among the major components of the KSTAR, the cryostat support beam, the cryostat base, and the magnet gravity support have been successfully assembled on the tokamak pit. Now, the TF magnet assembly that is the most critical phase in site work is underway. All TF magnets assembly will be finished by March 2006. Assembly operations conclude by August 2007 with the successful completion of the integrated system tests. The KSTAR is now preparing for the early stages of machine commissioning.

2. KSTAR superconducting magnet system

2.1. TF coil

The TF system consists of 16 TF coils that are electrically connected in series and is operated with 35.2 kA to give 3.5 T at major radius of 1.8 m. Nb_3Sn strand has KSTAR HP-III specifications in which the critical current density is higher than 750 A/mm^2 at 12 T, 4.2 K and 0.25% strain, and the hysteresis loss is less than 250 mJ/cm^3 at field variation from +3 to -3 T at 4.2 K. Two superconducting strands and one OFHC copper strand are cabled together to become a triplet in the first cabling stage. The cable pattern is $3 \times 3 \times 3 \times 3 \times 6$ of 486 strands. The major parameters of TF conductors and coils can be found in Ref. [1]. The total amount of Nb_3Sn and the total length of Incoloy 908 strip used for TF coil fabrication is about 19 tonnes and 12 km, respectively. Tube mill process is used for the fabrication of cable-in-conduit conductor (CICC), which consists of forming, welding, sizing and squaring procedures. The final dimension of the CICC is managed within an error of 0.05 mm and the void fraction of the CICCs is above 32%. The prototype TF coil test results showed that the void fraction of 32% is satisfactory for the coil cooling. The procedures of coil fabrication are summarized as follows: (1) CICC leak test, (2) CICC winding with zirconia bead grit blasting, (3) He feedthrough attachment and joint terminations, (4) reaction heat treatment for Nb_3Sn, (5) He leak test, (6) insulation taping and ground wrapping, (7) vacuum pressure impregnation (VPI), and (8) acceptance test and delivery. For the KSTAR TF magnet system, 19 TF CICC and 18 TF coils are required. Out of 18 TF coils, 16 are used for the main device, one for the real sized prototype and one for spare. One TF CICC spool and one TF winding pack are prepared as spare parts. Up to now one prototype TF coil and 16 TF coils have been fabricated. Now the final TF coil for spare is in the heat treatment process.

2.2. PF coil

The PF magnet system consists of eight central coils in the CS coil system and six outer PF coils. The CS (PF 1–4) and PF 5 coils use the same Nb_3Sn strands which used for the TF coils. The PF 6 and PF 7 coils use NbTi strands in which the critical current density is greater than 2700 A/mm^2 at 5 T, 4.2 K and the hysteresis loss is less than 200 mJ/cm^3 at field variation from +3 to -3 T at 4.2 K. The cable pattern of PF coils is $3 \times 4 \times 5 \times 6$ of 360 strands. Incoloy 908 and a modified stainless steel 316LN are used as conduit materials for PF $1 \sim 5$ CICC and PF 6, 7 CICC, respectively. Similarly, the major parameters of PF conductors and coils can be found in Ref. [1]. The total weights of Nb_3Sn strands for PF $1 \sim 5$ and NbTi strands for PF 6 and PF 7 coils are about 8 and 10 tonnes CICCs for two CS model coils (920 m × 2 m), PF 3 (290 m × 2 m), PF 4 (440 m × 2 m), PF 6 (1300 m × 4) and PF 7 (1700 m × 2 m) coils were already fabricated. CICCs for PF 1 (670 m × 2 m), PF 2 (550 m × 2 m) and PF 5 (1430 m × 2 m) are in the fabrication process. The