Status of the KSTAR Toroidal Field Coil Structure Fabrication

C. H. Choi,a J. W. Sa,a H. K. Park ,a K. H. Hong,a H. Shin,a H. T. Kim,a N. I. Her,a H. L. Yang,a J. H. Kwak,b H. G. Moon,b H. H. Yoon,b S. K. Lee,b J. Y. Song,b Y. D. Chu,b D. K. Hur, b K. M. Nam,b B. H. Koo,b J. H. Lim,b J. K. Lee,b N. G. Kim,b S. W. Jang,b H. C. Kim,b E. T. Ha,b J. S. Bak,a and G. S. Lee,a

a Korea Basic Science Institute, Daejeon, Korea,

b Doosan Heavy Industries & Construction Co., Ltd., 555 Gwigok-dong, Changwon, Gyeong -nam, Korea

chchoi@kbsi.re.kr

1. Introduction

The magnet system of the Korea Superconducting Tokamak Advanced Research (KSTAR) consists of 16 toroidal field (TF) coils, 4 pairs of central solenoid (CS) coils, and 3 pairs of outer poloidal field (PF) coils [1]. The dimensions of the TF coil structure [2] are 4.2 m in height, 3.5 m in width, and 22.5° in toroidal angle.

Representative allowable tolerances of an inboard leg and an outboard leg of the structure are ±1 mm and ±2 mm, respectively. Location tolerance of a toroidal ring basement that stands on a gravity support of the KSTAR magnet system is ±0.1 mm. Location and shape tolerances of shear key holes and conical bolt holes are ±0.1 mm and +0.03 ~ +0.07 mm, respectively. Angle tolerance for the toroidal angle of 22.5° is 0.015° that is absorbed by the insulation sheet.

2. Fabrication procedure

2.1. Before coil encasing

The TF coil structure consists of a case and a cover structures that are individually fabricated. The case structure that contains the coil is c-shaped and the cover structure is a plate. We have used forged blocks for upper and lower parts of the inboard leg and various thickness of plate for another parts of the structure. Most of the plates excepting these for intercoil structure have thickness margin of 5 ~ 7 mm for absorbing welding deformation. Narrow gap TIG welding is used. We use RT, UT, and PT as nondestructive examination for the welded zone. There are 18 cooling tubes with 8 mm outer diameter and 4 mm inner diameter embedded inside of the structure around the coil. Two cooling tubes with an outer diameter of 10 mm and inner diameter of 7 mm are attached on surface of the outer intercoil structure. The coolant is supercritical helium of 4.5 K. The TF coil structure has four types, because of different interface of the each structure with vacuum vessel slanted port, lateral support, and the CS and PF5 coil structures.

2.2. After coil encasing

We perform dimensional measurement, high voltage tests, and flow tests for acceptance test of the TF coil before encasing. The allowable dimensional tolerance of the TF coil after VPI is 2.0 mm. DC Hipot voltage is 15 kV and AC Hipot voltage is 10 kV (rms) for the ground insulation test. For the layer and turn-by-turn insulation test, the impulse voltage is 2 kV. The flow test is performed in room temperature with helium gas and the distribution of flow rate among cooling channels is maintained within 10 % variation at 8 bars.

The coil is inserted inside the case structure with a gap of 5 mm in the inboard leg and 10 mm in the outboard leg. The gap is needed to clear the fabrication tolerance of the coil and the structure. We installed various thicknesses of G10 spacers in the gap between the coil and the structure for alignment of the coil to the structure through the dimensional measurement. After the coil alignment with the spacers, the remaining space of the gap is packed with the glass felt to enhance mechanical strength of the epoxy. We have transferred coordinates of fiducial points of the coil to those of structures in order to define the axes of the structure. These axes are used as reference during the outer surface machining and assembly.

The enclosing weld was done with narrow gap auto TIG welding machine. After the enclosing weld, joint box cover plate is welded in joint box that contains the coil leads and the cooling lines of the coil and the structure. After installation of the cover plate, the structure has no clearance except periphery of the coil cooling lines. The clearance around the coil cooling lines is needed to allow movement between the coil and the structure. The movement generates a high stress in the coil cooling lines, which is originated by the in-plane and the out of-plane forces [3].

Figure 1. Enclosing weld process of TF structure

The gap packed with the glass felt is filled with the epoxy at the VPI process. One inlet stub with 10 mm diameter locates at bottom of the structure and two outlet stubs locate at the joint box. The structure is a vacuum chamber after closing around the coil leads and the coil cooling lines with a Room Temperature Vulcanizing. Target vacuum pressure for VPI is 9×10^{-3} mbar and leak rate is less than 1×10^{-8} mbar l/s. GY282/HY918 that is the same as the coil insulation has been chosen as the resin and hardener for the epoxy. 70 liters of the epoxy is filled for 12 hours at 40 °C. Curing of the epoxy was done at 90 °C for 8 hours and at 120 °C for the next 15 hours. We use a heat fan and wooden house for the curing and heat insulation, respectively.

We machine the outer surface of the structure with a Plano Miller as shown in Figure 1. The workable capacity of the machine is a length of 21 m, a width of 6 m, and a height of 5.5 m. Accuracy of the machine is 0.04 mm / 1000 mm. For precise assembly, every contact surface of the each structure should be machined accurately. Allowable tolerance of the surface is ±1 mm in the inboard leg and ±2 mm in the outboard leg with flatness of 0.5 mm. The tolerance is compensated by insulation plates of which designed thickness are 3 mm in the inboard leg and 4 mm in the outboard leg.

3. Intermediate results

We have encased seven coils that are TF00, TF05, TF04, TF06, TF03, TF07, and TF02 coils. The TF00 coil is a prototype. Measurement of the electrical resistance of ground insulation of the coil was performed before the encasing. The resistances of these coils were more than 10 GΩ at 0.5 ~ 5 kV, 1 minute. The average fabrication tolerance of these coils is less than ±1 mm and the standard deviation is about 0.5 mm. The average fabrication tolerance of inside of these cases is less than ±0.5 mm and the standard deviation is about 0.2 mm. The coils were aligned within ±0.5 ~ ±1 mm based on flatness, an inner wall of the inboard leg, and top and bottom of the case structures.

The TF00, TF05, TF04, TF06, TF03, and TF07 structures have been performed the enclosing weld process. For measuring temperature and stress of the TF00 structure during the enclosing weld, thermocouples and strain sensors were adhered on upper surface of the coil. The measured maximum temperature and stress on the coil surface were about 53 °C and 50 MPa, respectively. Measured deformations in width and height of the inboard leg were 2 mm and 1.5 mm, respectively. And those in the outboard leg were 1.5 mm and 2.5 mm, respectively. The glass felt was not burned but melted by the enclosing weld heat. The TF02 structure is in the enclosing weld process.

The TF00, TF05, TF04, TF06, and TF03 structures have been performed the VPI process. The vacuum pressure and leak rate of these structures was less than the target values. The vacuum degree was saturated to the target value after three days due to high impedance of the glass felt. The resistance of the coils ground insulation after the VPI was more than 10 GΩ at 1 kV, 1 minute. The TF07 structure is in the VPI process.

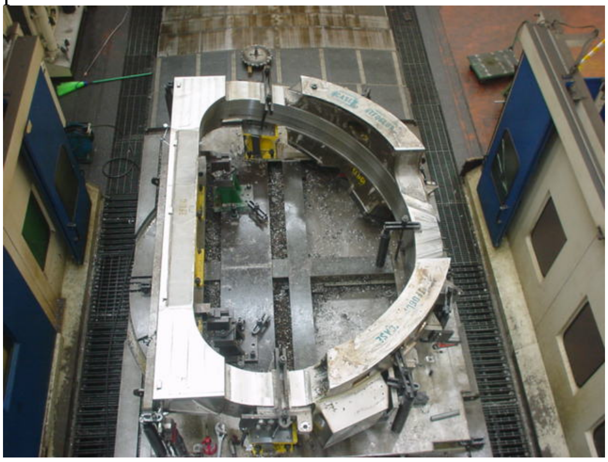

Figure 2. Outer surface machining process of TF structure

The TF00, TF05, TF04, and TF06 structures have been performed the outer surface machining process. During the machining, the structure set in three formations that are 0°, 11.5°, and –11.5° in contrast to radial centerline of the structure. It is very important to maintain the origin of the structure during changing the setting formation after machining in one formation. Flatness and angle tolerance of the structure are about 0.3 mm and 0.01°, respectively. We measured about 600 points of the structure with a laser tracker (Leica Co.). The TF03 structure is in the outer surface machining process.

3. Conclusion

We have completed fabrication of TF00, TF05, and TF04 structures. We have developed encasing process through the prototype structure fabrication. We have encased seven coils that are TF00, TF05, TF04, TF06, TF03, TF07, and TF02 coils. Present progress is about 58 %. The first TF coil structure will be assembled in March 2005. And the last structure will be assembled in February 2006.

REFERENCES

[1] J. S. Bak et al, Key Features and Engineering Progress of the KSTAR Tokamak, IEEE Trans. On Plasma Science, vol. 32, pp. 757, 2004.
[2] C. H. Choi et al., Fabrication of the KSTAR Toroidal Field Coil Structure, in Proceeding of IAEA Fusion Energy Conference, 2004.
[3] H. J. Ahn et al., Engineering Design Status of the KSTAR TF Coil Structure, IEEE Trans. Applied Superconductivity, vol. 12, pp. 492, 2002.