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Manufacturing and Assembly of KSTAR Superconducting Busline

S. W. Kwag, Y. M. Park, Y. J. Lee, Y. B. Chang, C. S. Kim, K. S. Lee, N. H. Song, E. N. Bang, H. T Park, C. H. Choi, and J. S. Bak
KSTAR, National Fusion Research Center, 52, Yeoeun-dong, Yusung-ku, Daejeon 305-333, KOREA
Sang8142@nfrc.re.kr

1. Introduction

KSTAR superconducting (SC) magnet system consists of 16 D-shape toroidal field (TF) coils, 4 pairs of central solenoid (CS) coils located at the tokamak center, and 3 pairs of poloidal field (PF) coils located on outer TF coils. Between current leads (CL) and SC coils, there are SC buslines that consist of out-of cryostat buslines (OCB) including vacuum ducts, thermal shields, and in-cryostat buslines (ICB). It has to carry currents through TF buslines up to 35.2 kA and 20 ~ 26 kA through PF and CS buslines. Since it flow DC currents through TF coils, where as, pulsed currents through PF and CS coils, OCB were divided by two, i.e., one for TF coils and another for PF and CS coils [1]. All the SC buslines were fabricated and assembled on the basis of various preliminary engineering works.

2. Configuration

It is presented the 3-dimensional configuration of the SC buslines in Fig. 1. In TF and PF OCB, there are 4 and 22 SC buslines, respectively. The buslines are to be cooled down to 4.5 K using super-critical helium supplied from helium refrigeration system (HRS) through helium transfer lines. Just bellow the main cryostat, the vacuum ducts, there are vacuum separators, and hence, the vacuum spaces of main cryostat and CLB are separated each other.

There are lots of support structures for ICB. Each pair of bus-lines is bundled together by mounting the composites of G10 block and stainless steel clamp to compensate repulsive magnetic forces when current flows in anti-parallel (Fig2).

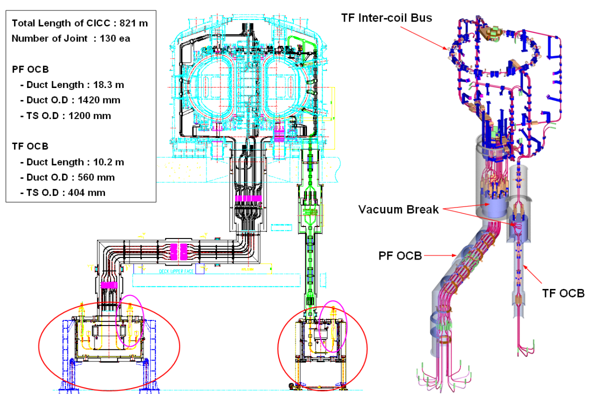

Figure 1. Three dimensional configuration of KSTAR SC bus-lines.

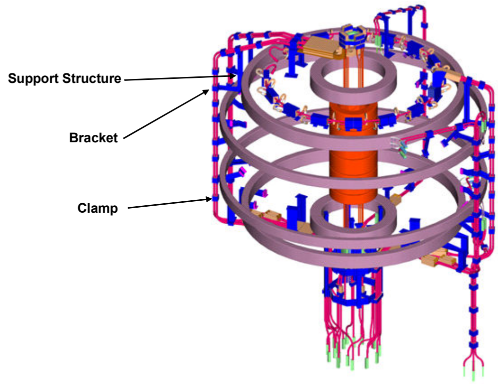

Figure 2. ICB CICC and support structure.

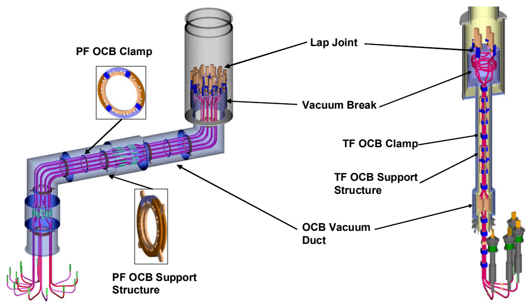

Figure 3. Three dimensional view of TF and PF OCB.

Each pairs of buslines are mounted on TF magnet structure using stainless steel supporting structure and G10 blocks.

3. Fabrication and Assembly

The OCB consists of vacuum duct, vacuum separator, aluminum thermal shields (TS), superconducting cable-in-conduit conductor (CICC), and G10 supports (Fig. 3). At outer surface of aluminum TS, it was assembled 30 layers of MLI those have the spacers that have a role to reduce thermal conduction between each layers of aluminized myler sheets. At vacuum separator, it is mounted stainless steel bellows for compensating mechanical stress due to cool down and radial electrical isolators for electrically isolating CICC from vacuum duct. Since the TF OCB is straight, CICC was helically bended one cycle to compensate mechanical stress due to cool down. Where as, PF OCB supports are not fixed to TS and vacuum duct since it could compensate the thermal stress through the bended CICC configuration.

3.1 In-cryostat busline

The CICC for busline has been fabricated as circular shape taken into account the complexity of routing and bending. It consists of seven sections of strands encased in 0.05 mm thick stainless steel (STS) tape and jacketed with 4.5 mm thick stainless steel 316L seamless pipe. In Fig. 4, one sub-cable section G that located at the center of CICC consists of 81 OFHC strands twisted as 3x3x3x3. The other 6 subcables surrounding the section G are cabled spirally with the length of one cycle 304 mm. The cabling pattern of 6 subcables is (2SC +1Cu)x3x3x3x6. Void fraction of the CICC was controlled close to 35% take accounting the effective heat exchange with helium coolants [2].

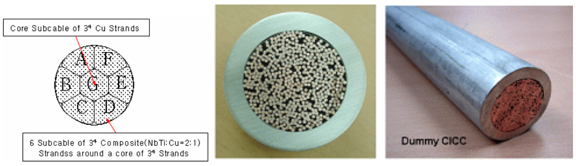

Figure 4. Superconducting cable-in-conduit conductor (CICC) for bus-lines.

At the end of CICC, it was assembled especially designed lap joint. The joining resistance was controlled to less than 2.5 $n\Omega$ concerning Joule heat and AC loss. Many lap joint samples were fabricated and tested at liquid helium temperature and real operating temperature (4.5 ~ 6 K) for the confirmation and the measured resistances were less than 2 $n\Omega$.

Stainless steel CICC jacket was electrically insulated using Kapton film and glass fiber tape. Total insulating thickness was 6 mm and the leakage currents throughout the CICC at 15 kV electrical potential was less than 1 μA. To minimize the contact resistance, copper surface of CICC strands and joining block was cleaned and silver plated with the thickness around 1 μm.

It is very critical in assembling CICC because of its own complicated bending configuration and many other pre-assembled components including SC coils. Especially, it required careful attention in joining two CICC to reduce assembly tolerance in longitudinal and circular direction since it gives direct impact on SC CICC reliability at operating currents. Before the assembly, stainless steel jacket at both end of CICC was removed and mounted mock-up joint to minimize assembly tolerance. After the assembly tests, it was mounted real lap joint on CICC. It was shown in Fig. 5 the assembly of in-cryostat CICC.

3.2 Out of cryostat busline

Vacuum separating part consists of vacuum shell, bellows, radial electrical isolator, supports, and thermal anchoring parts. The thickness of vacuum shell's cylinder part is 3 mm and there mounted 80 K thermal anchoring part between the cylinder part and OCB vacuum duct to reduce the heat flux from room temperature. Between bellows and CICC, it was assembled radial electrical isolator and the bellows part restricted the motion in radial direction by mounting stainless steel support.

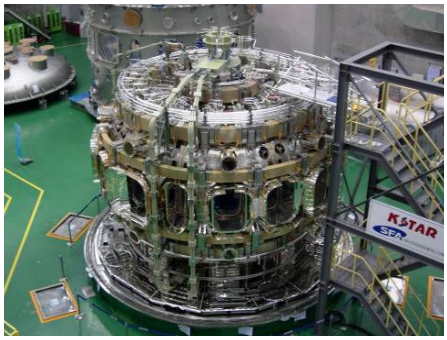

Figure 5. Assembly of the ICB.

Diameter of OCB vacuum ducts at the lap joining parts were enlarged and divided by to half cylinder for the CICC joint assembly (Fig. 1, 3, and 6). The two TF and PF OCBs were already assembled on site and confirmed the vacuum leak tightness, electrical isolation, and room temperature gas flow impedance of the CICC.

Figure 6. Assembly of TF and PF OCB.

4. Conclusion

KSTAR SC buslines were assembled on site and confirmed throughout room temperature tests. Lap joint samples were tested at cryogenic temperatures and the joining resistances satisfied the requirements. The SC busline is ready for cool down with the current lead system.

References

[1] Y. J. Lee, et al., "Development Status of the KSTAR Current Feeder System", 4th IAEA TM on SSO, FT5, (2005).
[2] Park, Y. M., et al., "Development Progress of the KSTAR Superconducting Magnet and Magnet Interfaces", 21th IAEA FEC, FT/P7-1, (2006).