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Engineering Progresses on KSTAR TF Inter-coil Bus and Joint

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1. Introduction

The KSTAR toroidal field (TF) magnet consists of 16 D-shape superconducting (SC) coils and all the coils are connected in series [1]. Between every two neighboring TF coils, there are 15 inter-coil buses and it was used NbTi/Cu SC cable-in-conduit conductor (CICC) same as that was used in buslines. In addition, two half-turn buses are connected to the remained two SC coil terminals and routed to be placed in the vicinity of the inter-coil buses to minimize the cross sectional area of closed loop build up between inter-coil buses and half-turn buses, and hence, to minimize enhanced electro-motive force (emf) at the closed loop due to magnetic field variation [2]. TF coil terminal and inter-coil bus was joined together using strand-to-strand (STS) joint as presented in Fig. 1.

2. Coil terminal preparation

TF coil terminals are located at the top regions. TF coil part SC CICC is Nb_3Sn/Cu, where as NbTi/Cu at inter-coil bus part. The terminal blocks of coil part are assembled before the coil heat treatment procedure. The terminal joining work should be done carefully because any mechanical stress could damage SC property of Nb_3Sn strands. All the terminal assembly procedures have been implemented by organizing previously well trained members.

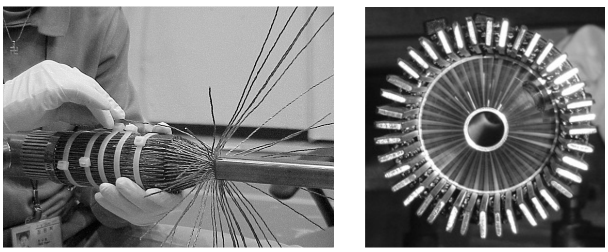

Figure 1. TF coil termination and preparation for joint installation

TF coil CICC has 486 strands inside [3]. At the terminal, 12 strands are soldered together and there are empty spaces between soldered strand groups which are filled with the strands coming from the inter-coil bus (Figure 1). Before soldering, the Cr plating layer on the strand was removed to lower the contact resistance. For the same reason, lots of cleaning works intervene. To minimize the oxidation of the strand surface in the coil terminal, it was soldered just after the removal of the oxidation layer using H_3PO_4 solution. High temperature 96.5Sn3.0Ag0.5Cu alloy solder to prevent low temperature lead alloy from dropping when the soldering together NbTi/Cu strand of the inter-coil bus. Low temperature lead alloy, which is soldering together the Nb_3Sn strands and NbTi strands, is pre-tinned on the Nb_3Sn strands of the coil terminals. After the soldering, it was cleaned with TCE solution since any remained impurities can influence on the helium coolant flowing inside the jacket of CICC. Fig. 2 shows the TF coil terminal, after high temperature alloy soldering and low temperature alloy pre-tinning.

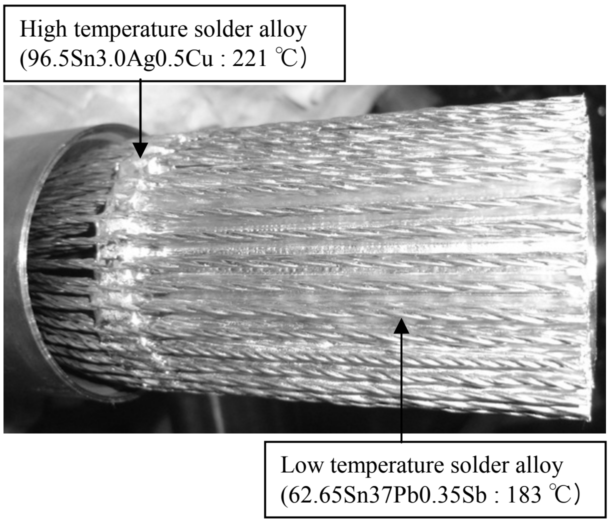

Figure 2. TF coil terminal after pre-soldering.

3. Inter-coil bus

Fig. 3 shows the 3-dimensional model of the KSTAR device with TF inter-coil buses.

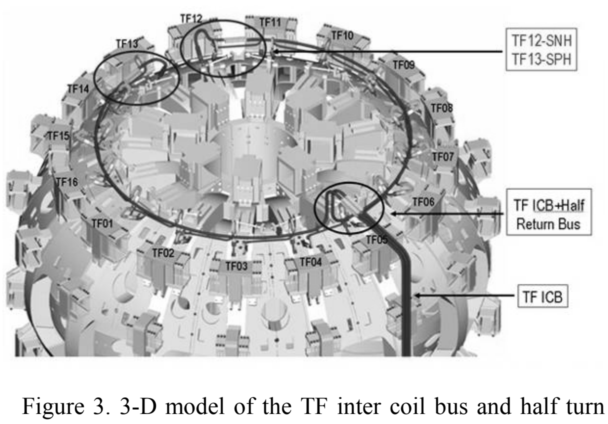

Figure 3. 3-D model of the TF inter coil bus and half turn bus

For the inter-coil bus, the same CICC as that for buslines were used as presented in Fig. 4. NbTi/Cu strands are cabled according to the scheme of 3x3x3x3x7. All the 81 strands, located center region, are OFHC strands, whereas 2 in 3 wires of the other sections surrounding the 81 strands are SC NbTi strands and the rest is OFHC strand. The final cable was wrapped with stainless steel film and inserted into 4.5 mm thick seamless stainless steel pipe. Void fraction of the CICC was controlled close to 35% for the effective heat exchange with helium coolants.

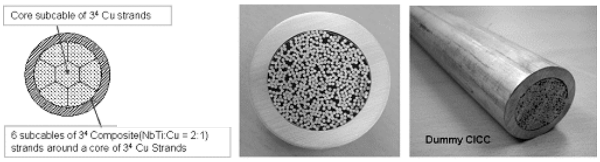

Figure 4. Superconducting CICC for bus-line

The CICC was bended using 3-dimensional bending tools minimum bending radius of 120 mm taking into account the mechanical stress on SC strands, void fraction reduction in the bended region, and so on. The stainless steel jackets at both ends of the CICC were removed to assemble it with the coil joint. In soldering the region where two kinds of strands from the coil and the bus are overlapping, it was used the solders with the melting points 183 ℃, which is lower than the former. Nevertheless, it can melt down the barriers of solder with higher melting point (Figure 2), which are placed on both sides of the overlapped region to prevent the coil CICC from being blocked by over-flooded solder. That is, when soldering inter-coil joint parts with lower melting point, the solder barrier or the interface of the two solders could melt down. Due to this reason, it was soldered discontinuously with soldering time of 30 ~ 60 s. After the finish of soldering process, it was cooled down quickly to the temperature lower than melting point using nitrogen gas and compressed air. Fig. 5 shows the STS joint sample and cross section of the soldering region.

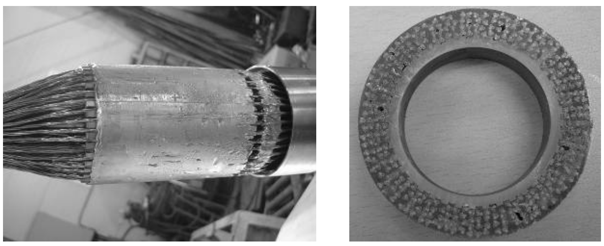

Figure 5. Soldering-finished STS joint.

When all the soldering works were finished, the soldered joint was covered with two stainless steel half cylinders, which were welded subsequently. When welding stainless steel jackets, it was monitored the welding temperatures and controlled the strands temperatures to be less than 100 ℃.

Both pressurizing tests and vacuum leak tests were done to confirm leak tightness, after finished stainless steel jacket welding. The CICC jackets of the inter-coil buses were electrically insulated by wrapping Kapton films and prepreged G10 tapes up to the thickness 6 mm, including joint terminal blocks. All the inter-coil buses are structurally supported using G10 case and stainless steel clamp to the TF coil structures. Fig. 6 shows the assembly of the inter-coil buses.

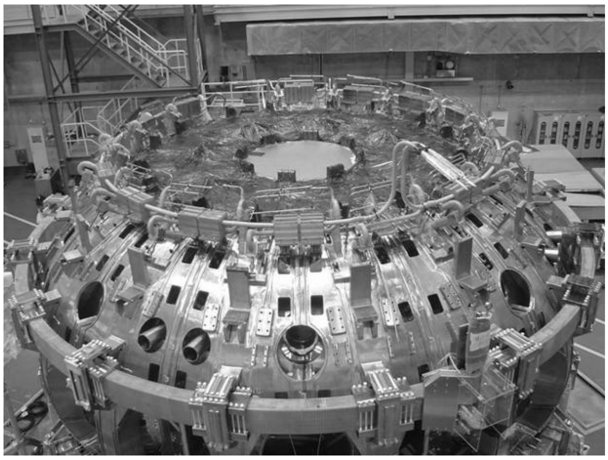

Figure 6. Assembly-finished TF inter-coil buses

4. Conclusion

All the inter-coil buses were assembled to the KSTAR TF coils using STS joining methods to reduce joint resistance less than 1 nΩ. Two half-turn buses were routed close to inter-coil buses to minimize emf and error fields. Room temperature test results satisfied KSTAR requirements and it is ready for cool down and current transmission.

References

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