Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006

Development of KSTAR Superconducting Busline Lap Joint

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

1. Introduction

It has been developed and tested the KSTAR lap joints that have a role to interconnect superconducting (SC) cables. Main goal in the lap joint development is the low DC joint resistance and AC loss. Problems in reducing the joint resistance are; high contact resistances due to Cr plated SC NbTi/Cu strands, soft soldering the strands and copper joint blocks, restricted size of the joint, and so on. To reduce the joint resistance it was improved the procedures such as removal of Cr layer, silver plating in the soldering region, adding pre-soldering process, and so on.

Two pair of joint samples which has same dimension as the final design of busline lap joint was prepared according to a manufacturing procedures and tested at liquid helium temperature. It was charged up to more than 400 A. Since the soft solders show super-conductivity, in general, it was tested at magnetic fields higher than critical fields of soft solders, i.e., around 0.2 Tesla.

2. Manufacturing Process

It is presented in fig. 1 the cross-sectional view of lap joint. It consists of stainless steel (SS) structures for the mechanical strength and a high purity copper block. Taken accounted the bulk resistance of copper block, it was used the residual resistivity ratio (RRR) higher than 100. Length of the joint block is around 300 mm. Copper block and stainless steel block is welded using e-beam welding (EBW) method in a vacuum state. SC strands are to be inserted in the half circled region of copper block before the assembly of upper half circled block made of SS. After the soft soldering between copper block and SC cable, upper SS block will be assembled. The joint block cab be assembled with another joint by bolting to blocks through the holes located both edges.

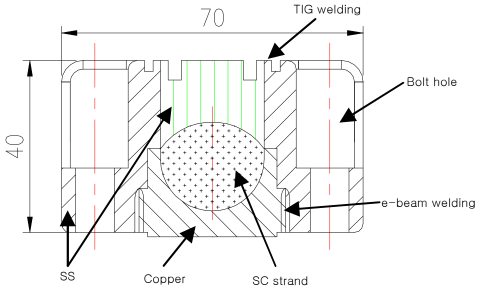

Fig. 1. Cross sectional view of lap joint.

Since the coolants super-critical helium (SHe) in a pressure around 3~5 bar and temperature around 4.5 ~ 5.5 K must flow through the SC cable, the void fraction inside the joint block was controlled to 25 ~ 27% after final assembly.

Detailed assembly processes are presented in table 1. It consists of SC cable-in-conduit cable (CICC) jacket removal, coated Cr removal of SC strands, Ag plating the SC strands and copper joint block, SC cable assembly, and joint-to-joint assembly.

2.1 Removal of CICC jacket and Cr

NbTi/Cu strands of CICC encased with thin SS tape and 5 mm thick SS jacket. Using especially developed tool, it was removed a little longer than joint block concerning the assembly. Since the SC strands coated with 1 μm thick Cr, it was removed by putting the strands into an acids such as HCL. After then, it was cleaned under the processes, ultrasonic cleaning and CN activation, to remove remained acids.

2.2 Silver plating

Cr removed strands and copper joint blocks were Ag plated following the process, Ag striking and plating, ultrasonic cleaning, and drying. Ag striking was done to help chemical bonding between silver and copper. Ag plating thicknesses of SC strands and copper joint blocks were 5~7 μm and 10 μm , respectively. The main reason why it was applied the Ag plating before the soldering is;

1) Reduction of contact potential.
2) Long term reliability in the soldering surface by protecting copper-tin alloy formation at copper-soft solder boundary.
3) Protecting oxidation at copper surfaces during processing.

Table 1. Lap joint assembly procedure.

1. CICC Jacket Removal	10. Cable assembly
2. Removal of Cr	11. Pre-soldering SC strands
3. Ultrasonic cleaning	12. Flux cleaning
4.CN activation	13. Cu block pre-soldering
5. Water washing	14. Flux cleaning
6. Ag striking	15. Soft soldering
7. Ag plating	16. Compressing and welding
8. Ultrasonic cleaning	17. Joint-to-joint assembly
9. Drying	

2.3 SC cable assembly

After the Ag plating, the SC strands were inserted into the copper joint block and compressed up to 500 ~ 600 bar to make good contact on the inner surface of hemi-circled copper block. This process is important since it is difficult to making same shape as the inner copper surface after pre-soldering.

For pre-soldering, compressed SC cable was disassembled. It was used 96.5Sn3.0Ag0.5Cu0.12Sb soft solder sheet melting at 221 ℃ and the thickness 0.2 mm. At surface to be soldered to copper block, two layers of the solder sheets were pre-soldered so that about three layers of SC strands from the surface soft soldered each others. This process is very important since it influence not only to joint resistance but also to void fraction of SC cable.

It was used same soft solders in pre-soldering the hemi-circled surface of copper block. After the pre-soldering, one layer of solder sheet was mounted in the copper surface to be assembled the SC cable and inserted again the SC cable. And then, it was mounted the upper SS cover and compressed so that the cable surface attached well to copper surface. During compressing it was heated up to soft solder melting point. The amount of soft solder was controlled and optimized to maintain the void fraction according to previous try and error processes.

Upper SS block was TIG welded after the soft soldering. Since the welding path is long, it was controlled the welding path length and periods to protect temperature rising and damaging due to welding. Throughout the welding process, it was mounted a temperature sensor and inspected the temperature of soldered region to be less than melting point.

2.4 Joint-to-joint assembly

Flat copper joint block surfaces were also pre-soldered before the joint-to-joint assembly and soft soldered the two joint blocks. In this case, it was used the soft solder melting at 183 ℃ so that the inner soft soldered region not to be melt down. For the mechanical reinforcement, the two joints were bolted together.

2.4 Lap Joint resistance measurement

Two lap joint samples were prepared for the joint resistance measurement. The joints were inserted into a liquid helium cryostat containing SC magnet. Lap joint block was in the liquid helium throughout the tests. It was charged up to more than 400 A in a magnetic fields 0.2 Tesla. It is presented in fig. 2 the test results. The voltage drop of the joint was measured using a nano-voltmeter. There was voltage shift, probably due to thermo-couple effect of the joint block made of different materials. So, it was measured at many applied currents and calculated the joint resistance by linear fitting I-V curves. As presented in fig. 2, the joint resistances at zero fields and 0.2 Tesla of the two samples in average were 1.5 nΩ and 1.8 nΩ. It satisfied the criteria 2.5 nΩ.

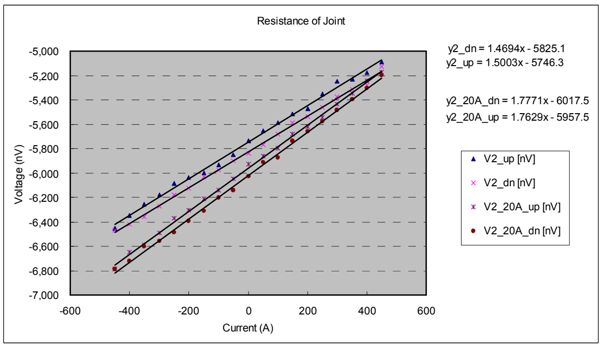

Fig. 2. Joint resistance test result.

3. Conclusion

It was developed and investigated the lap joint manufacturing process for KSTAR superconducting cable terminal interconnection. It was applied the silver plating and pre-soldering processes for the improvement of joint property and reliability. Two joint samples, same as the real joints, were manufactured and measured the resistance in applied magnetic fields. It satisfied the design criteria and requirements.