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

KSTAR Busline CICC Development

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

1. Introduction

It requires a superconducting(SC) cable-in-conduit conductor (ICCC) consists of NbTi/Cu strands, thin stainless steel (STS) tape, and STS jacket as shown fig. 1, table 1, and table 2. Total required length is around 1 km. Superconducting cable is divided by 7 sections; A ~ F sections consisted with NbTi/Cu strands and G section consisted with pure copper strands only. The design of A ~ F sections are same as that for superconducting coils. G section is added as the stabilizer. For the case of SC coil, the diameter of CICC is restricted due to overall size and the design value of magnetic field strength. However, SC busline is a little bit free from the restriction and much more important the stability against current charging. So, it was added the G section in busline CICC as a stabilizer.

In 567 total strands it contains 324 SC strands as shown in table 1. The strands in sections A ~ F are twisted as presented in table 1. The twist pitch is important since it influence to heat exchange efficiency and heat losses due to current charging and the variation of magnet fields. In 1^{st} stage, two SC strands and a pure copper strands are to be twisted each others with the twist pitch 40 mm. It is important since the first twist pitch directly influence to AC losses during current supply. In each sections, there are 81 strands twisted following four stages. Final twist pitch of A~G sections is 307 mm. Final twist pitch is one of important parameter in designing the terminal lap joint. Terminal lap joint length must be almost same or longer to reduce the joint resistance. If the joint length is too short, the electrical contact resistance between SC strands and copper block of the joint becomes higher since the strands are twisted and some portion of SC strands can apart longer than others from the copper joint block.

Another important parameter for the effectiveness of heat exchange between the strands and super-critical helium (SHe) flowing through the CICC is the void fraction inside the STS jacket. Design value is presented in table 2.

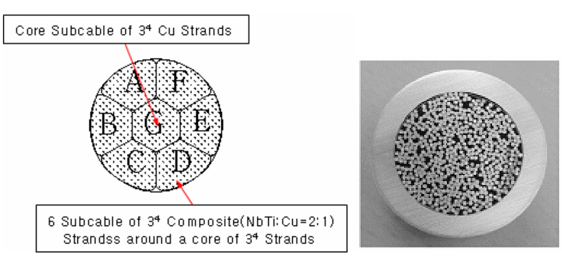

Fig. 1. Cross-sectional view of busline CICC.

Table 1. Construction of SC CICC.

Conductor parameters		
Items	Unit	
Superconductor		NbTi
Jacket		STS 316L
Diameter of strand	mm	0.78
Number of strand		567
Number of Superconducting strands		324
Number of copper strands		243
Thickness of final wrap	mm	0.05
Overlapping of the final wrap	%	40~50
Twist pitch		
1^{st} stage (3 (triplet))	mm	40±1
2^{nd} stage (3×3)	mm	73±2
3^{rd} stage (3×3×3)	mm	155±2
4^{th} stage (3×3×3×3)	mm	221±2
Final stage (3× 3 × 3 × 3 × 7)		307±3

Table 2. Design value of the CICC void fraction.

Void fraction parameter		
Cable space inside jacket, A_0	mm^2	438.84
Jacket inner diameter	mm	23.6
Cross sectional area of strand, A_{strand}	mm^2	270.9
Cross sectional area of final wrap, A_{final_wrap}	mm^2	7.6
Twist angle, cos θ		0.976
Cross sectional area of internal components	mm^2	277.59
Cross sectional area of void, A_{void}	mm^2	153.56
Void fraction, V	%	35
Perimeter of strand, P_{strand}	mm	1389.4
Perimeter of jacket, P_{jacket}	mm	74.27
Effective wetted perimeter, P_e	mm	1248.2
Hydraulic diameter, D_h	mm	0.492

2. Manufacturing process

Superconducting strand cabling was done in a Korean company as the same way and dimension presented in table 1 and 2. Cabling was done without any disconnected region in the strands with the length round 1 km. During cabling it was inspected the criteria such as twist pitch at each twisting stages and controlled the overall diameter to around 24 mm.

After then, unjacketed cable was cut to suitable lengths, around 7 ~ 13 m, according to the design of busline routing. Maximum cutting length was around 10 m. As the jacket, it was used the shim-less STS pipes with the length, outer diameter, inner diameter, and thickness are, 10 m, 34 mm, 25 mm, and 4.5 mm, respectively. Bare SC cable was inserted into the pipe using especially prepared inserting tool. To reduce the friction in inserting, it was introduced a vibrator on to the pipe. When inserting the cables longer than jacket pipe, the pipe was enlarged by welding another pipe to the end as shown in fig. 2. After the welding, it was removed the beads formed inside the pipe concerned the strands damages when inserting.

It is presented the cable inserting photos in fig. 3. Before inserting the cables, the cable ends were swaged less than the inner diameter of STS pipe. At this region, pulling cable was assembled and inserted into the pipe, first. In inserting bare CICI, it was issued the friction force. To solve the problem, the pipe was vibrated and sprayed alcohol into the pipe throughout inserting process. Vibrating jacket pipe was very effective in reducing friction force and hence the pulling force was negligible compared to allowable tension of the bare CICC.

After the insertion of bare SC cable, CICCs were put into compaction roll to reduce the jacket diameter and hence to get wanted void fraction as table 2. Jacketed CICC were vacuum leak tested. Both ends of the jacket were vacuum tightened with especially designed and fabricated blanket sealed with viton O-ring. Before the vacuum leak test, it was pressurized up to 35 bars with helium gases and sprayed to welding points the soap bubble for visible leak check. The leak rates measured with vacuum leak detector were less than design criteria 1E-9 mbar-l/s.

It also inspected the real void fraction as presented in table 3. Three samples with different lengths were prepared and measured the volumes of each component by putting them into a water cup. Measured values were very close to the design value 35% as shown in table 3. There was no any remarkable sample length dependency.

Fig. 2. Photos of jacket pipe welding.

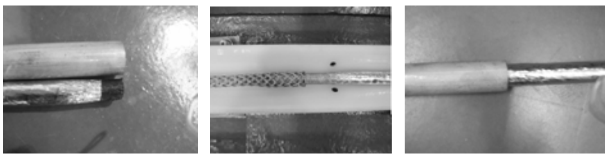

Fig. 3. Photos of bare CICC inserting.

Table 3. Void fraction measurement result.

Sample No.	1	2	3
Void fraction [%]	35.0	35.4	35.2
Total volume [cc]	16.6	32.9	49.4
Conduit volume [cc]	7.9	15.8	49.4
Volume of strands and STS tape [cc]	5.6	11.1	25.7
Length [mm]	20.0	40.0	60.0

3. Conclusion

Full length of superconducting CICC for busline was developed and tested the physical parameters. It satisfied the design criteria of 1^{st} and final stage twist pitches, 40 mm and 307 mm, respectively. It also satisfied the required void fraction 35%. All the jacketed CICC were vacuum leak tested and passed the requirements, 1E-9 mbar-l/s. Using this CICCs, it’s now being under the construction of buslines.

REFERENCES