DEVELOPMENT OF SC BUS-LINE FOR THE KSTAR SUPERCONDUCTING MAGNET *

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Abstract

A superconducting (SC) bus-line, which is a current feeder between the SC coils of the Korea Superconducting Tokamak Advanced Research (KSTAR) device and the current lead system, was designed. The SC bus-lines have 7 ducts and 12 pairs of cable-in-conduit conductors (CICCs), which are made of NbTi/Cu CICC cooled with forced-flow supercritical helium (SHe). The bus-line has independent vacuum space and consist of SHe return line and 60 K thermal shield. We have developed a prototype SC bus-line interface terminal that is to connect the bus-line with the KSTAR cryostat and current lead box. It consists of vacuum break, electrical break and flexible structure. We performed the thermal and structural analysis for the vacuum break. The fabrication, assembly, and cool-down tests of the SC bus-line interface terminal were carried out. The interface terminal was cooled with forced-flow gas helium until 10 K after pre-cooling with liquid nitrogen. Heat load of thermal shield was measured.

1 INTRODUCTION

In general, many devices of using the large superconducting magnet require long current feeder system to connect coils and power supplies with large current capacity. A current feeder usually consists of water-cooled bus bars and current leads. The water-cooled bus bar needs a large cross-sectional area, which is 250 mm^2 per 1 kA, and loses a colossal electrical energy by the joule heating [1]. In large fusion devices using superconducting (SC) coils, the function of the current feeder system is to transfer a large amount of current from power supply to the coils without energy consumption.

The KSTAR (Korea Superconducting Tokamak Advanced Research) device requires also a current feeder system. The KSTAR SC magnet system consists of 16 toroidal field (TF) coils, 4 pairs of central solenoid (CS) coils and 3 pairs of outer poloidal field (PF) coils. All the SC coils, using cable-in-conduit conductors (CICCs), are cooled with forced-flow supercritical helium (SHe). The conductor of the TF coils and CS-PF5 coils is Nb_3Sn superconductor with Incoloy 908 conduit, whereas that of the PF6 and PF7 coils is NbTi superconductor with stainless steel 316LN conduit [2]. The 16 set of TF coils are connected in series and operated with 35.2 kA. The PF coils have an up-down symmetry and the operating current is about 20 ~ 25 kA [3].

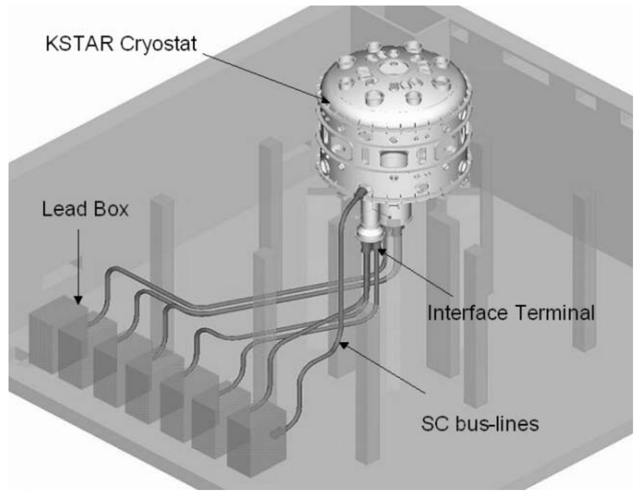

Figure 1: Configuration of the SC bus-line system for the KSTAR device.

The current feeder system of the KSTAR SC coils needs much more excellent stability and safety than the coils themselves. When the emergencies such as the coil quench or a suddenly power failure occur, the large magnetic energy stored in the coils must be extracted through the current feeder system [3].

In this paper, we report development of SC bus-line system for KSTAR device.

2 DESIGN OF SC BUS-LINE

The main function of the SC bus-lines in the current feeder system of the KSTAR device is current transmission from the current lead to the SC coils. The SC bus-line system consists of SC bus-line, in-cryostat bus, and interface terminal. Figure 1 shows the configuration of the SC bus-line system.

2.1 SC Bus-line

The SC bus-lines have 7 ducts and 12 pairs of CICCs. Because the 16 TF coils are connected in series, only one pair of CICC is necessary to transmit current for the 16 TF coils. The other ducts for the PF coils include two pairs of CICCs. Table 1 shows the specification of the bus-lines. The bus-lines consist of SC conductor, thermal shields, electrical insulations, and support structures. Figure 2 shows 3-dimensional structure of the SC bus-line. The SC conductor is a square-shaped CICC, with 324

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Table 1: Number of the SC bus-line for the SC coils

Coil	Connection	CICC	No. of Bus-line
CS1 (U, L)	serial	1 pair	1
CS2 (U, L)	serial	1 pair	
CS3 (U, L)	parallel	2 pairs	1
CS4 (U, L)	parallel	2 pairs	1
PF5 (L)		1 pair	1
PF6 (U, L)	parallel	2 pairs	1
PF5 (U)		1 pair	1
PF7 (U, L)	serial	1 pair	
TF	serial	1 pair	1

NbTi strands, 162 copper strands, and 6 internal voltage taps in a stainless steel 316LN conduit. Two pairs of CICC are separated with spacer, and insulated with kapton and E-glass tape by 50% over wrapping. Kevlar tape used to bind the repulsive electromagnetic force between two pairs of CICC. The bus-line duct for vacuum insulation is flexible corrugated tube. The average length of the bus-line duct is about 30 m and the total length is about 200 m. For the higher thermal stability than that of the coils, the bus-lines are designed to have a double thermal shield system that consists of an inner and outer screen with multi-layer insulation. The inner screen is connected to the SHe return (~6 K) through a bus-line CICC, and the outer screen of thermal shield serves as 60 K shield by using a gaseous helium. The inner and the outer screen have flexibility to compensate the thermal contraction due to cool down. The support structure and spacer are made of GFRP (G-10).

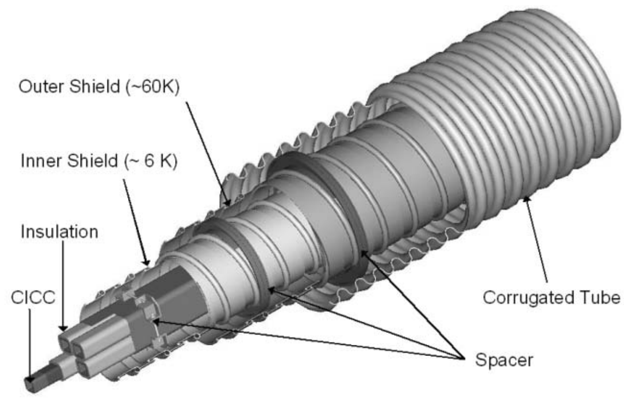


Figure 2: Three-dimensional view of the SC bus-line.

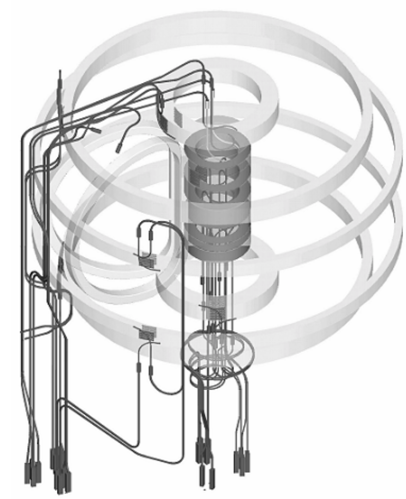


Figure 3: Three-dimensional view of the in-cryostat bus.

2.2 In-cryostat Bus

In-cryostat bus is to transfer current from the SC bus-line interface terminal at cryostat boundary to the SC coil termination. The in-cryostat bus has been designed to be able to compensate the thermal contraction stress due to the cool-down from 300 K to 4.5 K. Figure 3 shows the routing of the in-cryostat bus. In-cryostat bus consists of CICC, which is used the CICC of SC bus-line. Each CICC of the in-cryostat is insulated with the kapton and E-glass tape.

2.3 Interface Terminal

The real size prototype of SC bus-line interface terminal that is to connect the bus-line with the cryostat of the KSTAR and current lead box has been developed. It consists of vacuum break, electrical break, and flexible structure to satisfy following requirements.

- The vacuum break serves to keep independent vacuum space for the bus-line in order to operate the bus-line safely when the KSTAR cryostat vacuum was broken.
- The electrical break is insulator to break the induced eddy current at the cryostat due to the pulse mode operation and to cut the current flow to the vacuum break, which is connected to CICC.
- Convenient maintenance should be required for the long operation of the device.

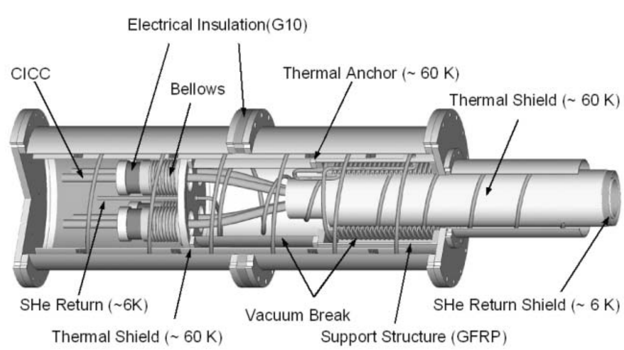


Figure 4: Three-dimensional structure of the prototype interface terminal.

Figure 4 shows a 3-dimensional structure of the prototype interface terminal. The electrical break at CICC part in the interface terminal is designed to resist over a 15 kV breakdown voltage, which is the requirement of the KSTAR SC coils, and is made with G10 and SS316L by VPI (Vacuum Press Impregnation) method. The eddy current due to the pulse operation of the coils is cut off by another electrical break, GFRP. The thickness and the inner diameter of GFRP are 30 mm and 504 mm, respectively. The vacuum break is classified to two parts by thermal anchor in the middle of break. The bellows part reduces heat transfer from room temperature to

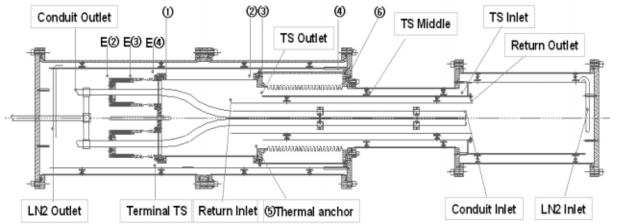


Figure 5: The position of temperature sensor in the interface terminal.

thermal anchor temperature by making long path. The GFRP structure of the vacuum break part supports the bellows and another part. The thermal shield of the interface terminal is connected with bus-line thermal shield through the thermal anchor.

3 COOL-DOWN TEST OF THE REAL SIZE PROTOTYPE INTERFACE TERMINAL

The full-scale model of the interface terminal was constructed to implement the feasibility and performance test. We carried out cool-down test for the prototype interface. The interface terminal was cooled with forced-flow gas helium until 10 K after pre-cooling with liquid nitrogen. Figure 5 shows measuring points of temperature at the interface terminal.

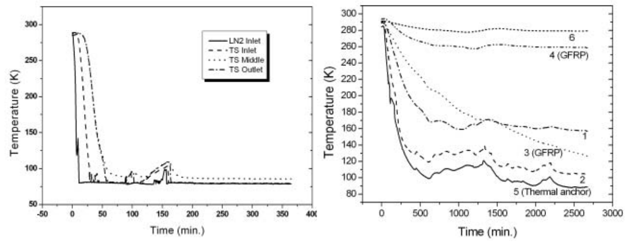
3.1 Pre-cooling

The interface terminal was cooled down from the room temperature to the liquid nitrogen temperature within 45 hours by using liquid nitrogen. Liquid nitrogen was supplied to two inlets, LN2 and conduit Inlet, then to be turned out LN2 and return outlet, respectively.

Figure 6 shows temperature profile during the pre-cooling process. The temperature of thermal shield was stabilized after 200 minutes from cool-down. The abnormal temperature around 150 minute was due to the exchange the liquid nitrogen dewar. The temperature sensor on the middle of thermal shield (TS) was located 10 cm away from cooling line of the thermal shield. The measuring temperature was 7 K higher than inlet temperature. The heat load to the thermal shield without MLI was 10 W/m^2. The temperature of thermal anchor stabilized at 87 K. The part ① and the part ② at the vacuum break had higher temperature than the thermal anchor. It appears that stainless steel has low thermal conductivity, and will be cool down after long time.

3.2 Cool-Down

Figure 7 shows the temperature profile at the conduits and the return shield during cool-down, and the flow rate of the gas helium. In order to measure the temperature-raising trend, cut off the LN_2 supply during 200 minutes before cool-down with cold gaseous helium. After the cutting off of the LN_2 supply, the inlet temperature of the conduit keeps nearly constant. It is ascertained that double thermal shield is sufficiently shutting off heat transfer



(a) (b)

Figure 6: Temperature profile of (a) thermal shield and (b) vacuum break during the pre-cooling.

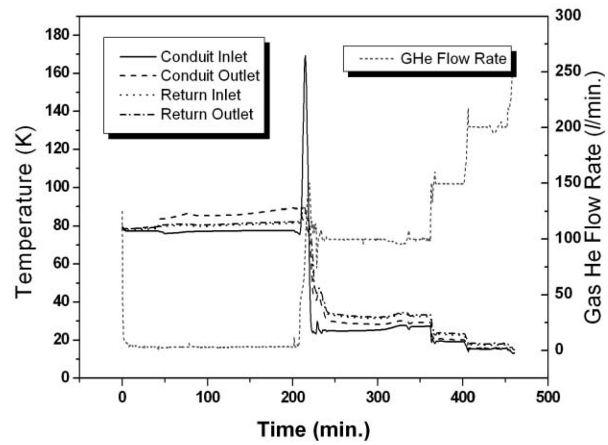


Figure 7: Temperature profile of the conduits during cool-down by using cold gaseous helium after pre-cooling.

to the conduit. But there was small temperature increase on the conduit outlet, the return inlet and the outlet. The conduit and the return shield were cooled with forced-flow gaseous helium until 10 K.

4 CONCLUSIONS

The SC bus-line was designed for the KSTAR device. The real size prototype of SC bus-line interface terminal had been fabricated and checked assembly possibility at on site and tested cool-down performance.

5 ACKNOWLEDGMENT

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6 REFERENCES

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