Results of Preliminary Testing of Blip and Cancellation Coils for the Samsung Superconductor Test Facility (SSTF)

S. Baang, S. Lee, W. Chung, K. Kim, Q. Wang, M. P. Alexeev, O. P. Anashkin, D. P. Ivanov, V. E. Keilin, V. V. Lysenko, S. M. Miklyaev, I. O. Shchegolev, V. I. Shcherbakov, S. A. Shevchenko, I. O. Shugaev, and M. I. Surin

***Abstract*—The background magnet system of SSTF (Samsung Superconductor Test Facility) for KSTAR (Korea Superconducting Tokamak Advanced Research) will be equipped with a pair of main coils (MC) and a pair of blip coils (BC). The main goal of the BC is to simulate electromagnetic disturbances (1 T amplitude and 20 T/s discharge rate), expected from the KSTAR operation. The coupling losses and magnetic interaction between MC and BC will be decreased by resistive cancellation coils (CC) wound onto a fiberglass bobbin. The BC is wound with a cable in conduit conductor (CICC) packed with Nb_3Sn strands. A set of BC and CC was tested in an open type cryostat. The BC is cooled with both boiling LHe in a container and pressurized helium passing through the CICC. The BC was charged up to 6.7 kA and discharged in 50 ms. During the discharge, the maximum field variation rate corresponds to 28 T/s in the BC center and 53 T/s on the BC conductor. No quench was observed and the BC was recharged in less than 1 minute. The measured shielding current in the CC is in a good agreement with the calculated value.**

***Index Terms*—Blip coil, cancellation coil, KSTAR, SSTF.**

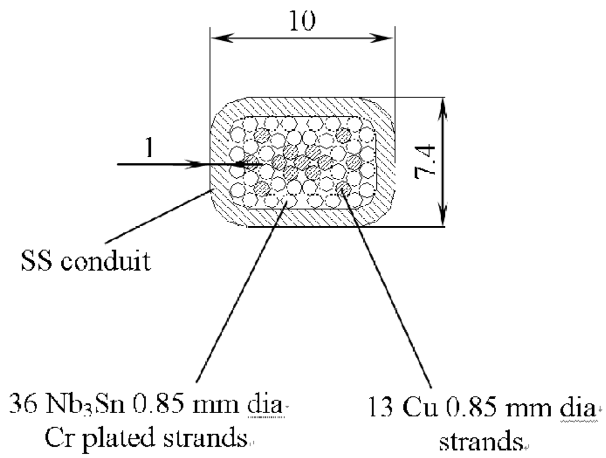

Fig. 1. BC conductor cross-section (unit: mm).

I. Introduction

SAMSUNG superconductor test facility (SSTF) has been constructed at Samsung Advanced Institute of Technology (SAIT) for the test of high current superconducting conductor samples and their joints, as well as model coils and full scale superconducting magnets for KSTAR (Korea Superconducting Tokamak Advanced Research) [1], [2], which is under construction at Korea Basic Science Institute (KBSI) located at Taejon, Korea.

SSTF has a 6 m in diameter, 8 m height cryostat and the background magnet system which includes [3], [4]:

1) Main coils (MC) with inner diameter 740 mm providing background field up to 8 T in the 250 mm gap between two MC halves. These two halves of MC are almost full scale models of KSTAR central solenoid (CS) sections. They are made from the same cable-in-conduit-conductor (CICC) planed to be used for CS and should have the field ramp up rate up to 3 T/s.

2) Superconducting transformer (ST) to supply the currents up to 50–70 kA to the sample conductors [5], [6].

3) Blip coils (BC) placed inside MC also consist of two halves with the same gap between them as that of MC halves. These coils provide the operating space 250 mm $\times$ 400 mm (in diameter) with the additional field $\pm$1 T directed along the main MC field axis at the ramp rate up to 20 T/s to simulate the disturbances from KSTAR superconducting magnets during plasma initiation and disruption.

4) Passive cancellation coils (PCC) displaced co-axially between MC and BC reduce the disturbances onto MC during fast BC discharge, such as stray field variation and high voltage induction [7].

The last two magnets are made as one construction unit encased in thin wall tank which is to be filled up with boiling LHe to cool them. This unit is placed and fixed inside of MC.

The description of BC and PCC design, the methods of their fabrication and the self-field test results of their first halves are presented below.

II. BC and PCC Design Requirements and Description

BC should work in the field up to $\sim$10 T, which is produced mainly by MC as well as by BC themselves. Also, they should

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S. Baang was with Samsung Advanced Institute of Technology, Taejon 305-380, Korea. He is now with Hallym University, Chuncheon 200-702, Korea (e-mail: baang@hallym.ac.kr).

S. Lee is with Samsung Advanced Institute of Technology, Taejon 305-380, Korea (e-mail: silee@samsung.co.kr).

Q. Wang is with the Institute of Electrical Engineering, Chinese Academy of Sciences, Beijing 100080, China (e-mail: qiuliang@mail.iee.ac.cn).

M. P. Alexeev, O. P. Anashkin, D. P. Ivanov, V. E. Keilin, V. V. Lysenko, S. M. Miklyaev, I. O. Shchegolev, V. I. Shcherbakov, S. A. Shevchenko, I. O. Shugaev, and M. I. Surin are with Kurchatov Institute, 123182 Moscow, Russia (e-mail: kev@isssph.kiae.ru).

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TABLE I
BC CONDUCTOR MAIN PARAMETERS

Parameter	Units	Value
Dimensions	mm × mm	10 × 7.4
Conduit thickness	mm	1
Conduit material		SS
Conduit cross-section	mm^2	28.3
Number of sc strands		36
Number of Cu strands		13
Strands cross-section	mm^2	27.8
He cross-section	mm^2	14.5
Copper cross-section	mm^2	12.5
Void fraction	%	34

TABLE II
FINAL DATA OF THE STRAND FOR BC CONDUCTOR

Parameter	Units	Value
Strand diameter	mm	0.85 ± 0.01
Amount of copper	%	25 ± 2
Cu : nonCu ratio		1:3
RRR		> 100
Number of filaments		25531
Critical current @ 10 T	A	> 400
Hysteresis losses @ ± 3 T	mJ/cm^3	< 600
Twist pitch	mm	10 ± 1
Cr plating thickness	μm	1

withstand very fast field variation, up to 50 T/s (at the coil) without the transition to the normal state [4].

At the same time, they should have high current density to produce the required field strength taking into account the hard space restrictions to put both BC and PCC coils inside of MC. The currents in these coils have to be rather high, not less than 5 kA, to restrict the voltage induced on BC during fast discharge.

To satisfy all the requirements a special CICC type conductor has been designed and made for BC. The cross section of this conductor is shown on Fig. 1. The specifications of the conductor are given in Table I.

The superconducting strands are Nb_3Sn wires, designed and produced by Bochvar Nonorganic Materials Institute. The final data of the strands for BC conductor as well as some characteristics of the manufactured strands are given in Tables II and III.

The BC is supported in operating position by fiber glass (FG) bobbins and flanges. To withstand the strong radial forces due to the interaction with the MC field, the BC are strengthened by insulated stainless steel wire bandage wrapped around the coil. Main parameters of BC as a whole are given in Table IV.

The PCC is wound using high RRR copper with 18 mm × 7 mm cross section to allow the induced current during fast BC discharge. It rises rather fast, within ∼10 ms, up to about 6 kA and then decays with the time constant ∼0.1 s which could be regulated by the dump resistors located outside of the cryostat.

TABLE III
CHARACTERISTICS OF THE MANUFACTURED BC CONDUCTOR STRAND

Set #	Length (m)	Copper fraction (%)	NonCu cross-section (mm^2)	$J_{c\,nonCu}$ @ 10 T (4.2 K, ε = 0:A/mm^2)	$J_{c\,nonCu}$ @ 10 T (ε = −0.002:A/mm^2)	Hysteresis losses @ ±3 T (mJ/cm^3)
110	806	25.3	0.424	961.8	926.5	572
115	867	23.6	0.434	926.8	892.8	597
117	1184	24.1	0.431	1012.6	975.5	550
301	945	25	0.426	960.3	925.1	–
386	563	23.1	0.435	1042.4	1004.2	586
388	1641	23.9	0.432	998.5	961.9	–

TABLE IV
MAIN PARAMETERS OF BC AND PCC

Parameter	Units	BC	PCC
Inner diameter	mm	352	640
Outer diameter	mm	448	668
Height	mm	132	288
Number of turns in each coil		72 (6 layers)	24 (1.5 layers)
Number of turns in each layer		12	16[a] / 8[b]
Operating current	kA	5.64	3.8[c]

[a]Full layer. [b]Half layer. [c]Maximum induced current.

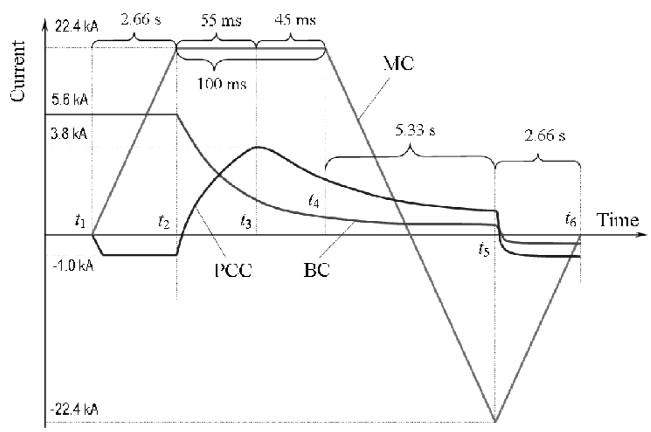
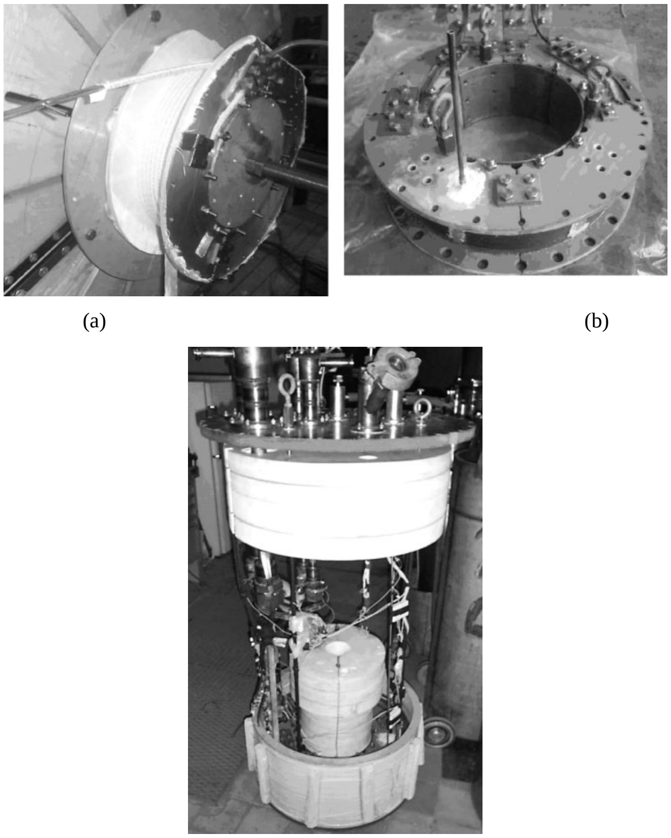


Fig. 2. Operation scenario of MC, BC and PCC.

Therefore, the heating of the PCC and the amount of LHe evaporated could be kept low, when they are operated following the scenarios of MC, BC and PCC, as in Fig. 2. The PCC decay time, t3 in Fig. 2, can be reduced considerably by increasing the dump resistor with the help of additional switch.

The PCC is fixed in operating position and assembled together with the BC by FG bobbins, flanges and clamps. Both the BC and the PCC are cooled by boiling LHe filled in the thin wall vacuum tight tank enclosing them. Additional cooling is provided to the BC by pushing supercritical helium flow through the conductors. Before going into the BC, helium flows through a heat exchanger immersed in LHe to remove the heat coming into the helium flow during the long communication passes from the refrigerator.



(a) (b)

(c)

Fig. 3. BC coil fabrication: (a) winding with insulated CICC, (b) installation of fiber glass flanges after the reaction, and (c) test preparation of BC and PCC after the impregnation.

The BC and the PCC magnets are equipped with several diagnostics: voltage taps, thermometers, Hall probes, He flow and level meters, etc.

III. BC Fabrication

The "reaction after winding" method is used for the BC coil fabrication to save the high current carrying capacity of Nb_3Sn wires of the conductor. On the other hand, to avoid BC heating and quench during fast field variation, the FG supporting structure has to be used, because even the SS flanges with the cuts could cause a dangerous temperature rise.

To solve these contradictory requirements, it is suggested to take two steps of fabrication. At first, the coil insulated by dry glass fibers and clothes is wound onto a steel bobbin which is consisted of a number of parts. After the winding, usual heat treatment is made: using a vacuum tight chamber filled in by helium gas, inside an oven. The heat treatment regime has two preliminary steps at 250 °C and 500 °C and the highest heat treatment temperature is 650 °C lasting 200 hours.

After cooling down, the steel structure was carefully removed and replaced part by part with FG structures supporting the coil and inlets/outlets. Only after this, the magnet was impregnated with resin and cured.

Photos from the different stages of BC manufacturing are displayed in Fig. 3.

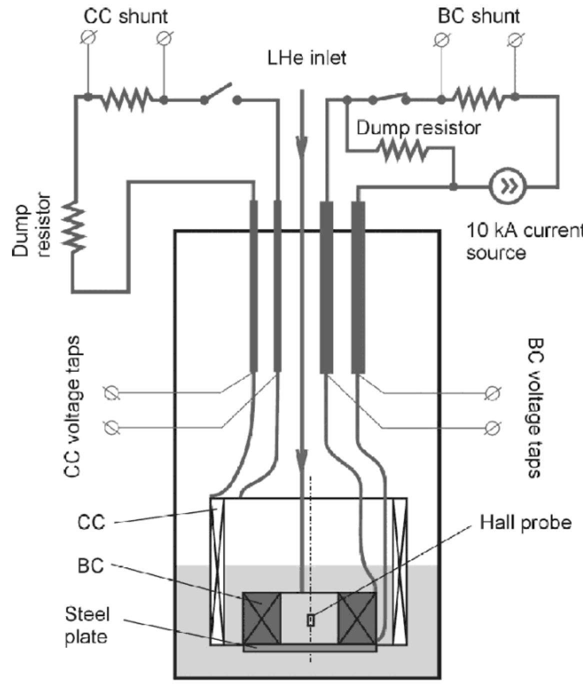


Fig. 4. Schematic diagram for the test of BC and PCC.

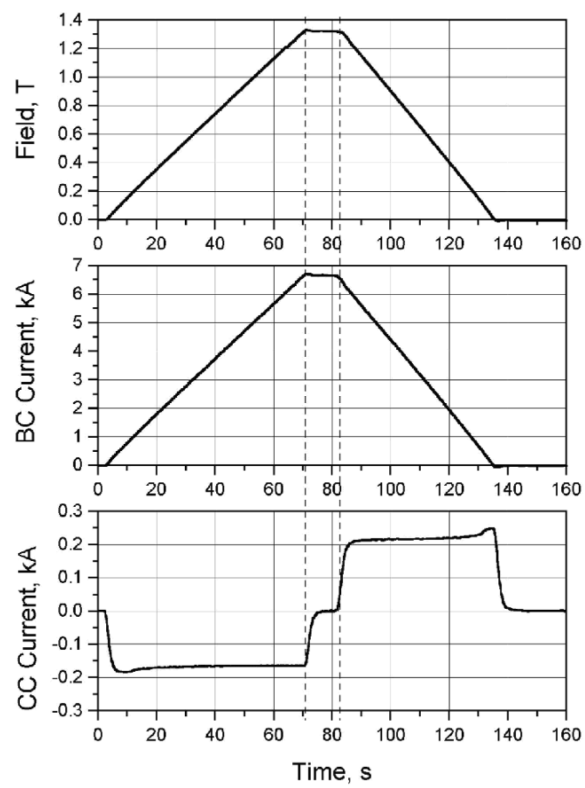


Fig. 5. BC self-field test: slow charging with PCC short circuited.

IV. BC and PCC Preliminary Test

A set consisting of the first halves of BC and PCC is tested in an open type cryostat using the coils' own magnetic fields; self-field test. To simulate at least partly the real field distribution for the case of two BC halves as well as the forces acting on the coils in real operating conditions, an iron plate, 40 mm

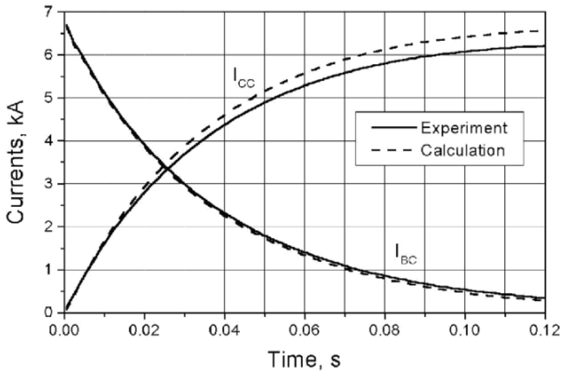


Fig. 6. BC self-field test: fast discharge and PCC charging.

thick, is placed at one side of test set. The schematic diagram of experiment is shown in Fig. 4. The cryostat is partially filled with boiling LHe. Then, additional cooling of BC is provided by pushing LHe from a transport dewar through CICC.

Slow charging of BC up to 6.7 kA under the influence of its own magnetic field and slow discharging have been tested successfully as shown in Fig. 5.

In the next experiment, fast discharge tests in 50 ms from different levels of current are realized. Finally, the discharge from the current level 6.7 kA at the flat top is shown in Fig. 6. During this discharge, the maximum field variation rates corresponding to 28 T/s in the BC center and 53 T/s on the BC conductor are achieved. No quenches are observed and BC are ready to recharge in less than 1 minute. The BC behavior during charging and fast discharge are smooth, showing good quality of magnet, though the $B \cdot I$ products in these experiments are smaller than those from the real operating conditions by a factor of at least two because of the absence of main background field.

The shielding currents measured from the shunt in PCC circuit are in good agreements with calculated values. This shows an effective protection provided by PCC. No high helium evaporations have been observed even without the increase of the damping resistor in the PCC circuit.

V. Conclusion

The self-field tests of BC and PCC have shown that 1) BC can withstand very fast field variation up to 53 T/s without transition to the normal state, 2) PCC can provide effective protection of MC from disturbances produced by fast BC discharges, and 3) the heating of PCC and the amount of helium evaporation are quite small.

The characteristics of coil obtained without the main background field show good qualities and good agreement with calculations and, thus, allow the expectation that they could work in real operating conditions as well.

References

[1] S. Baang *et al.*, "The test facility for the KSTAR superconducting magnets at SAIT," *IEEE Trans. Appl. Supercond.*, vol. 10, no. 1, pp. 645–648, March 2000.

[2] J. H. Schultz *et al.*, "The KSTAR superconducting magnet system," in *Proc. of MT-15*, Beijing, China, 1997.

[3] S. Baang *et al.*, "The background magnets of the Samsung superconductor test facility (SSTF)," *IEEE Trans. Appl. Supercond.*, vol. 11, no. 1, pp. 645–648, March 2001.

[4] "KSTAR magnet system review,", Aug. 25–27, 1999.

[5] S. Baang *et al.*, "The conductors of the 50 kA superconducting transformer for SSTF," *Physica C*, vol. 354, pp. 105–109, 2001.

[6] ——, "The superconducting transformer of the Samsung Superconductor Test Facility (SSTF)," *IEEE Trans. Appl. Supercond.*, vol. 11, no. 1, pp. 1494–1497, March 2001.

[7] ——, "The comparison of active and passive cancellation coils for SSTF," IEEE Trans. Appl. Supercond., to be published.