§25. Design Study of a 15 T Test Facility for High-current Superconductors

Imagawa, S.

Future fusion power plants need larger scale and higher field superconducting magnets than ITER magnets, the highest field and conductor current of which are 11.8 T and 68 kA for TF coils and 13.0 T and 45 kA for CS coils. It is well known that the sufficient length of testing area is necessary to examine the superconducting properties of large conductors. Therefore, the existing 9 T test facility in NIFS is planned to be upgraded to 15 T solenoid coils with the large cold bore of 0.7 m, as shown in Fig. 1. The existing 9 T split coils are replaced to a set of solenoid coils. The length of testing area exceeds 1.5 m by adopting conductor samples with coil shape even in the case of one turn coil. The 15 T coils are designed to be divided into two parts, which are the inner coil and the outer coil. The larger coil sample can be tested at 7 T with only the outer coil.

High coil current density of 70-90 A/mm^2 is needed to attain 15 T at sample position, the radius of 0.30 m, under the restriction of the outer diameter less than 1.3 m. The highest field of 7 T is suitable for the outer coil made of NbTi conductors to increase the average current density. A design example is shown in Table 1. The magnetic field at sample position is 14.7 T when the center magnetic field is 14.0 T, as shown in Fig. 2. The highest field in the coils is 14.99 T. When only the outer coil is installed, 7.4 T can be generated at the radius of 0.44 m. The total weight of the coils is estimated at 8.0 tons.

Rutherford cables are candidates to attain the high current density. An external protective resistance is used for the coil protection. In order to suppress the discharge voltage less than 800 V, the operating current is set at 6 kA, which is the nominal current of the existing power supply. The copper current density of the conductor is set at 112 A/mm^2 to suppress the hotspot temperature below 200 K at the discharge time constant of 16 s. In these design criteria, the expected current densities are 65 A/mm^2 for the inner coil and 81 A/mm^2 for the outer coil, by increasing the load factors, I_{op}/I_c (the operation current / the critical current) to 88% and 81%, respectively. These high factors seem marginal for the high field magnets. The thickness of inside coil cases is 10 mm including the ground insulation, and that of outside case is 30 mm to withstand the strong magnetic force. The detailed mechanical analysis is a future work.

The highest field in the outer coil can be reduced by adopting longer inner coil than the outer coil. In the case as shown in Table 1, it is reduced to 7.08 from 7.7 T by elongate the length from 1.0 to 1.2 m, and the load factor on the loading line of the outer coil is reduced from 87% to 81%. Therefore, the optimization of the coil figure is important to increase the stability margin with reducing the amount of superconductors.

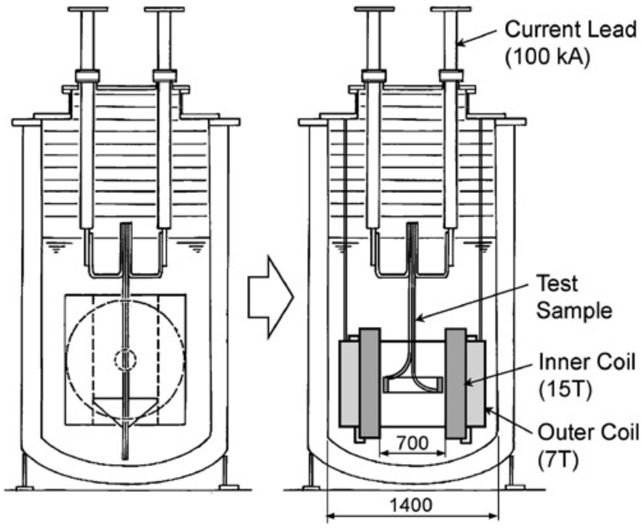

Fig. 1. Upgrading plan of the conductor test facility by replacing the 9 T split coils to 15 T solenoid coils.

Table 1. Specifications of the solenoid coils

	Inner	Outer
Field at sample position (T)	14.7 at 0.3 m	7.4 at 0.44 m
Maximum field (T)	14.99	7.09
Cold bore diameter (m)	0.7	1.001
Stored energy (MJ)	14.4	23.1
Self inductance (H)	0.801	1.283
SC material	Nb_3Al (or Sn)	NbTi
Operating current (A)	6000	6000
Cu/SC ratio (-)	1.573	3.71
Iop/Ic on the load line (%)	88.4	81.4
Temperature margin (K)	1.70	1.06
Winding inner diameter (m)	0.720	1.021
Winding outer diameter (m)	0.941	1.212
Winding length (m)	1.2	1.0
Magnetomotive force (MA)	8.67	7.79
Coil current density (A/mm^2)	65.5	81.5
Conductor size (mm^2)	40	52.2
Thickness of insulation (mm)	0.2	0.2
Conductor length (km)	3.78	4.58
Highest voltage (V)	581	762
Weight (tons)	4.0	4.0

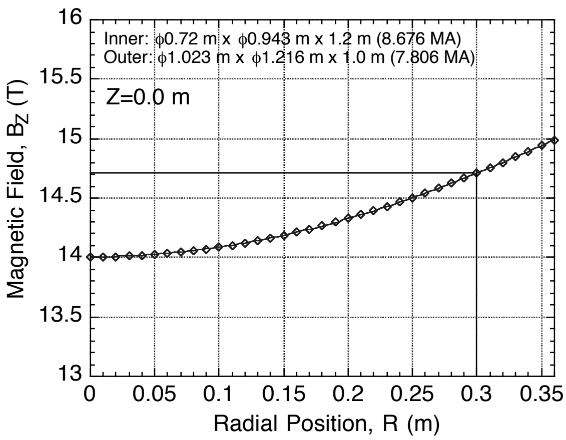

Fig. 2. Magnetic field distribution at the middle in the case shown as Table 1.