§9 The First Generation of Magnetic Field of LHD

Imagawa, S., Chikaraishi, H.

After the coils were completely cooled down and liquid helium was stored sufficiently, the first excitation tests of superconducting coils were conducted. The power system consists of two pairs of helical coils (HCs), three pairs of poloidal coils (PCs), nine superconducting power cables (SC Bus-line), six thyristor rectifiers with local control units and a central control unit, as shown in Fig. 1. In order to change the current center and to reduce the voltage to earth during the current shut-off, each HC is divided into three blocks that are called H-I, H-M and H-O. Since the mutual coupling factor during the blocks is larger than 0.9, each current is easy to transfer to the other. For attaining accurate control of the current, we should know the self and mutual inductance precisely. The other major feature is that the time constant of the secondary circuit made of the supporting structures is in the order of 1 s. We should consider the secondary circuit in the case of rapid control. Each power supply has an own local unit to control the current and voltage. In order to realize non-interactive control during the six power supplies, the necessary voltages are calculated by the central control unit from the measured currents by using the inductance matrix.

Since the testing period was limited within six days, test patterns of currents were rationalized. The HCs and PCs are designed to be cryostable at 4.4 K for 3 and 4 T operation, respectively. In order to establish reliability of the whole system of LHD before 3 T operation, plasma experiments in the first and second cooling cycle had been determined to be carried out at 1.5 T of the central toroidal magnetic field. The current shut-off from high magnetic field generates high voltage in the coils and large amount of AC losses in the coils and supporting structures, therefore, the reliability of the power system and cryogenic system are very important. Then, the first generation test of magnetic field was limited to 1.5 T. The test currents at 1.5 T and the design values are listed in Table 1. Since the cryostability of coils at 1.5 T operation is very high, the delay time detecting a coil quench can be elongated from 1 s to 5 s for avoiding miss-trigger caused by a signal noise.

At begin, each pair of coils was excited up to 1 kA by the local control unit for adjusting the feedback gain of the local control. Next, all coils were simultaneously excited by using the central control unit. It took two days to revise the fatal error in the program. In the debugging process, the control scheme was simplified from the optimal feedback control to simple P control. After adjusting the feedback gain of current control in excitations up to 0.05 T, the coils were successfully excited up to 0.2, 0.5 and 1.5 T in a day. The current pattern of the first 1.5 T excitation is shown in Fig. 2. The current accuracy is listed in Table 2. In order to have priority on the stability, the feedback gain was selected to be small. Accordingly, the settling time was much longer than the target value for field changing operations, and the accuracy of current control is short of target value. However, it is sufficient for the first plasma experiments in constant field, because the current stability was very good.

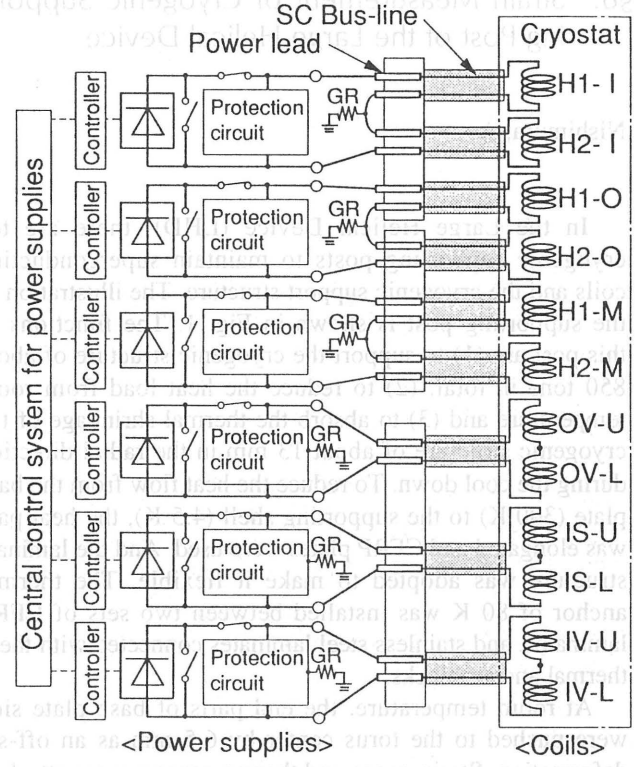

Fig. 1. Diagram of power system of LHD.

Table 1 Test currents and design values of coils

coils		test current at 1.5 T #1-o	test current at 1.5 T #1-b	design value (at 4.4 K)
H-I	(kA)	6.5	6.5	13.0
H-M	(kA)	6.5	6.5	13.0
H-O	(kA)	6.5	6.5	13.0
OV	(kA)	-10.2	-9.09	-31.3
IS	(kA)	-2.58	-7.97	-21.6
IV	(kA)	5.34	7.58	20.8

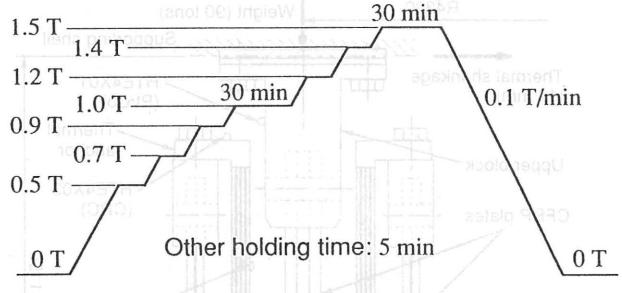

Fig. 2. Current pattern of the first excitation up to 1.5 T.

Table 2 Current accuracy of power supplies

item	results at 1.5 T	target value
Voltage ripple (V)	0.5	< 0.5
Control error (%)	0.2(HC)/0.3(PC)	< 0.04%+6 A
Current stability (%)	< 0.05	–
Settling time to 1% off (s)	< 60	1