§3. Improvement of Cryogenic Stability of LHD Helical Coils by Lowering the Outlet Temperature from 4.4 K to 3.9 K

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In order to improve the cryogenic stability of the LHD helical coils, an additional cooler at 3.0 K was installed before the tenth cool-down.[1)] The inlet and outlet temperatures of the coils were successfully lowered to 3.2 K and 3.8 K, respectively, with a mass flow of 50 g/s. In spite of a half charging rate to reduce AC losses, a normal-zone has been induced near the top of the coil at 11.4 kA while the outlet temperatures was raised to 3.95 K by mainly the increased hysteresis losses, as shown in Fig. 1. The local temperature of the innermost layers near the top is considered to have been raised up to almost the saturated temperature of 4.4 K due to the losses and the natural convection. Therefore, the excitation method was revised in the latter half of the tenth campaign. By holding the current at about 11.0 kA for more than two hours for cool-down, the excitations up to equivalent 11.5 kA have been attained.[2)]

Following the eleventh cool-down, excitation tests were carried out to check the soundness of the magnets. In the first excitation to #1-o 2.70 T, that is, 11.25 kA of the helical coil current to examine the change of conductor movement of the helical coils, short length propagation of a normal-zone was observed at 11.17 kA and 11.21 kA of the helical coil currents. They are 20th and 21st propagation listed in Table I. This excitation pattern has been carried out as the first test in each cooling cycle, and a normal-zone had not been propagated in this pattern before. The behavior of conductor motion is considered to be changed. Besides, propagation of a normal zone was observed at 11.0 kA at plasma-axis of 4.1 m, as shown in Fig. 2(b). Its condition and the propagation behavior are similar as the 17th propagation in 2003. Therefore, the cryogenic stability of the helical coil was not deteriorated.

In subcooling operation, propagation of a normal-zone was observed at 11.4 kA from the bottom of #10 sector, as shown in Fig. 2(a). Its propagation length is the shorter than that at 11.0 kA in saturated helium, as shown in Fig. 2(b). The level of pickup coil signals in the former is obviously less than that in the latter, which means the length of the propagating normal-zone is shorter in subcooling operation. Therefore, it is confirmed that the cryogenic stability was improved by subcooling. However, the improvement is weaker than the prospect from the test results with a model coil. The reason is under consideration.

1) Imagawa, S. et al., Nuclear Fusion **47** (2007) 353.
2) Imagawa, S. et al., IEEE Trans. Appl. Supercond. **18** (2008) 455.

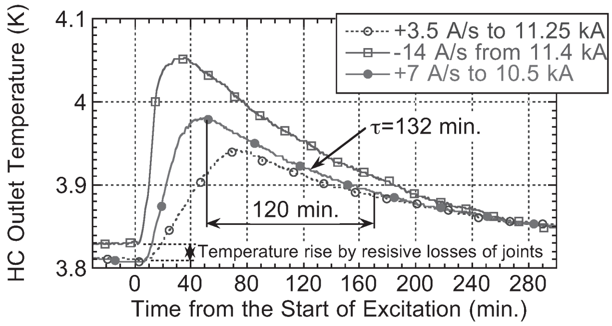

Fig. 1. Temperature rises at the helical coil outlet.

Table I. Propagation of normal zones in the LHD helical coils since 2001. The 20th to 24th propagation occurred in the 11th campaign. The 18th, 19th and 23rd propagation occurred while being cooled by subcooled helium.

No.	Mode	H-O/M/I current (kA)	Coil	Position
10th	#1-c_R4.1 m	11.16/ ← / ←	H1-I	#10 bottom
11th	#1-o_γ1.258	11.71/11.57/10.94	H1-I	#10 bottom
12th	#1-o	11.04/ ← / ←	H1-I	#10 bottom
13th	#1-o	11.15/ ← / ←	H1-I	#10 bottom
14th	#1-d	11.30/ ← / ←	H1-I	#10 bottom
15th	#1-c	-11.08/ ← / ←	H2-I	#5 bottom
16th	#1-o	-11.11/ ← / ←	H2-I	#5 bottom
17th	#1-c_R4.0 m	11.00/ ← / ←	H1-I	#10 bottom
18th	#1-o_-2.747 T	-11.45/ ← / ←	H2-I	#8 top
19th	#1-d_R3.65 m	11.75/11.35/11.35	H1-I	#3 top
20th	#1-o_2.68 T	11.17/ ← / ←	H1-I	(#4 sector)
21st	#1-o_2.69 T	11.21/ ← / ←	H1-I	#10 bottom
22nd	#1-c_R4.1m	11.06/11.00/11.00	H1-I	#10 bottom
23rd	#1-o_2.75 T	11.53/11.40/11.40	H1-I	#10 bottom
24th	#1-o_-2.666 T	-11.37/-10.97/-10.97	H1-I	#10 bottom

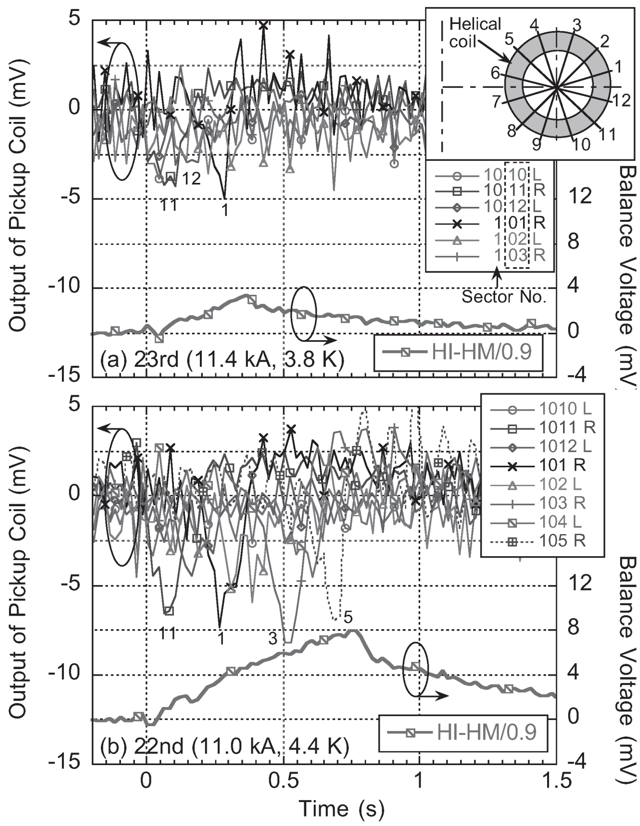

Fig. 2. Output of pickup coils and balance voltage of the helical coils during the (a) 23rd and (b) 22nd propagation of a normal zone.