§4. Achievement of 2.9 T@3.6 m Operation with Sophisticated Monitoring of Balance-Voltage Signals in the LHD Superconducting Helical Coils

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In order to improve the cryogenic stability of the bath-cooled helical coils of the Large Helical Device (LHD) and to realize higher magnetic field operations [1], a sub-cooled liquid helium production unit was installed in the valve-box in 2006 [2]. With the supply of sub-cooled liquid helium with an inlet temperature of 3.2 K, we carried out higher-field excitation tests and successfully achieved up to 11.46 kA of the helical coil current. During these tests, short-duration normal-zones still appeared with sub-cooled operations. We consider that this was due to the temperature rise of the helical coil windings by the AC losses generated during excitations. Thus, it was decided to wait for more than two hours after an initial excitation up to the 2.5 T level before further raising the field.

In the 11th operation cycle conducted in 2007, we planned to achieve 11.6 kA current on average, which corresponds to the toroidal field of 2.9 T with the magnetic axis positioned at the major radius of 3.6 m. In order to achieve this goal, we carried out excitation tests on six days during the plasma experimental period, and tried to climb to the summit gradually. In each excitation test, we carefully monitored the balance-voltage signals of the helical coils, and applied the pulse height analysis to quantitatively evaluate the mechanical properties of the windings [3] along with excitations. Figure 1 shows the variation of the cumulative spike signals observed in excitation tests with the innermost (H-I) blocks of the LHD helical coils during the past nine cycles, and the variation in the higher field tests conducted in the 11th cycle is shown in Fig. 2.

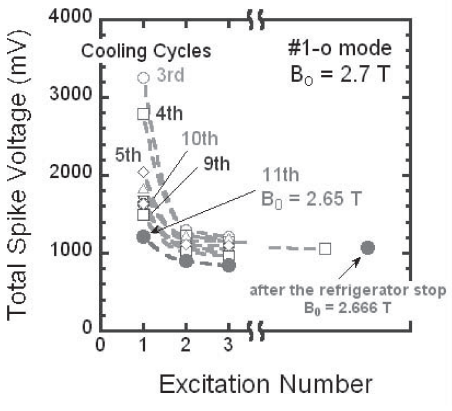

Fig. 1 Variation of cumulative spike signals observed in excitation tests with H-I blocks of the LHD helical coils.

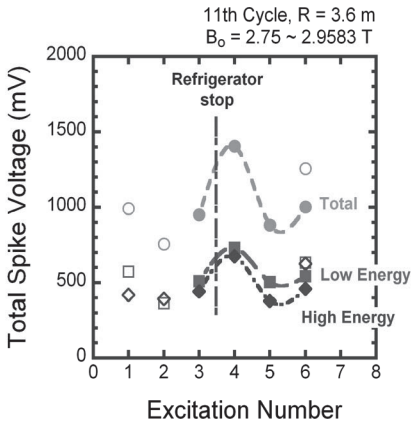

Fig. 2 Variation of cumulative spike signals observed with the H-I blocks in high-field excitation tests.

Figure 3 shows the waveforms of the balance-voltage signals of H-I and H-M blocks during the excitation test that achieved 2.9 T. Here, we first reached a bit higher field of 2.9583 T by having the currents of H-O/M/I = 12.4/12.0/11.1 kA. This was to apply bigger electromagnetic forces to the windings so that they would not further move along with the increase of the H-I current while decreasing the H-O current. Then, we finally achieved H-O/M/I = 11.4/12.0/11.4 kA that corresponds to the average current of 11.6 kA and the field of 2.9 T.

During these excitation tests, it was confirmed that normal-transition was not observed. A PC-based data acquisition system for automatic detection of normal-transition was fully utilized and the balance voltage signals were analyzed in real-time [4].

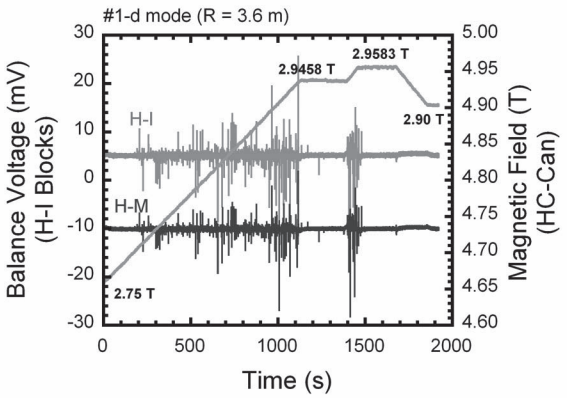

Fig. 3 Balance-voltage signals of H-I and H-M blocks during the excitation that achieved 2.9 T@3.6 m.

1) Imagawa, S. et al., IEEE Trans. Appl. Supercond., 14 (2004) 1388.
2) Hamaguchi, S. et al., Fus. Eng. and Des., 81 (2006) 2617.
3) Yanagi, N. et al., Fus. Eng. and Des., 81 (2006) 2561.
4) Yanagi, N. et al., NIFS Annual Report (2007).