§7. Sophisticated Monitoring System for Detecting Normal-Transitions in the LHD Superconducting Helical Coils

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During the former nine experimental cycles of the Large Helical Device (LHD), stable operations have been performed with the bath-cooled helical coils for producing high-temperature and high-density plasmas. However, seventeen times of normal-transitions have been observed at the current level slightly lower than the specified value [1]. It should be noted that only one event did not recover (which initiated the emergency discharging process), whereas in other events, the normal-zone appeared within a couple of seconds, and then it naturally recovered back into the superconducting state. In order to improve the cryogenic stability of the helical coils, an upgrade program has been implemented for the cryogenic system before the tenth operation cycle. Two centrifugal cold-compressors with gas-foil bearings were installed into a newly situated liquid helium tank connected to the original valve-box unit [2]. The liquid helium supplied to the valve-box is cooled through a heat exchanger, and the inlet temperature of the helical coils is 3.2 K.

With the supply of subcooled liquid helium, we conducted excitation tests by aiming at achieving higher current of the helical coils than the previous results, and we have reached up to 11.46 kA (toroidal field: 2.75 T with #1-o mode). However, we observed a “small” normal-transition just before achieving this point, as is shown in Fig. 1. Here, the word “small” is used in the meaning that it is much smaller than the condition for the judgment of a quench (voltage: 200 mV and duration: 2 s). Due to the specific geometry of the conductors used for the helical coils, it is not sufficient to analyze only the balance voltage for obtaining the resistive component. It has been found that the subtractive signal between the two balance voltage signals of H-I and H-M blocks can be a good measure to more precisely evaluate the resistive component. In the case of Fig. 1, the resistive component of ~ 5 mV was found with a ~200 ms duration.

By having observed such a “small” normal-transition, we found that it was rather difficult to detect such an event every time by human eyes. In this connection, we have developed an automatic detection system of normal-transitions by analyzing the balance voltage signals in real-time with a newly installed PC-based data acquisition system (shown in Fig. 2). A threshold condition can be given as 2 mV and 100 ms for the subtractive signal of the balance voltage of H-I and H-M blocks. This condition has been determined by analyzing all the former data of normal-transitions. As is indicated in Fig. 1, the “small” normal-transition of this case could have been detected with the present system. In the analysis, other signals, such as spike signals caused by conductor motions and/or electrical noises can be excluded with the present threshold condition. However, there are two kinds of examples that give misjudgments. One is due to the relatively significant noises in the balance voltage signals due to plasma discharges. And the other is due to flux jumps in the conductors. We are currently trying to develop suitable algorithms to distinguish these events from normal-transitions. Moreover, we consider that pick-up coil signals can also be used for more directly making a real-time judgment. We expect that the present system will be effectively used from the next experimental campaigns.

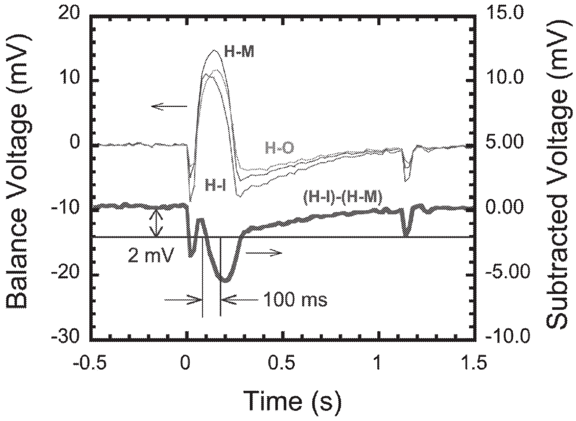

Fig. 1 Waveform of the balance voltage signals at the normal-transition. The subtracted signal is the difference between the balance voltage signals of H-I and H-M blocks.

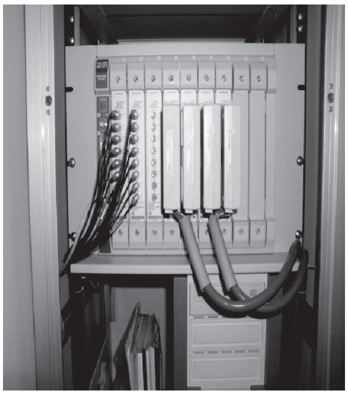

Fig. 2 New data acquisition system for the real-time judgment of normal-transitions.

References
1) Imagawa, S., et al., IEEE Trans. Appl. Supercond., 14 (2004) 1388.
2) Hamaguchi, S. et al., Fusion Engineering and Design, 81 (2006) 2617.