§5. AC Losses in Poloidal Coils of the Large Helical Device

Takahata, K., Chikaraishi, H., Mito, T., Imagawa, S.

AC losses in poloidal coils of the Large Helical Device (LHD) have been measured during single-pulse operations. Superconductors of the poloidal coils are Nb-Ti cable-in-conduit conductors (CICC) cooled by supercritical helium. In 2008, the voltage output of power supplies for the poloidal coils was enhanced to control the magnetic field structure rapidly during plasma experiments. The maximum rate of field change was 0.06 T/s in an innermost conductor, which corresponds to a 6-fold increase compared with previous operations. This enhancement also enables AC loss measurements during more rapid pulse operations.

The losses can be measured by monitoring the enthalpy increase of helium coolant between inlet and outlet.[1] The coolant is always driven out from the outlet. Therefore, the total losses can be obtained by:

$$Q = \int m\Delta H dt \qquad (1)$$

Where m is the mass flow rate and ΔH is the enthalpy increase due to the losses. Fig. 1 shows an example of time evolution of the enthalpy variation for the IV-L coil. After a single pulse operation, increase of $m\Delta H$ was observed for about 1500 s. The offset of 15 W corresponds to heat leak by conduction and radiation, Q_L. The integration of ($m\Delta H - Q_L$) gives the total losses.

Fig. 2 shows the total measured losses versus $1/\tau_0$, where τ_0 is defined as the time period during which the current increases or decreases. The maximum currents were fixed at 2 and 4 kA. Hysteresis losses are independent of a sweep rate. Therefore, the hysteresis losses can be experimentally obtained by extrapolating the $1/\tau_0$ dependence on the measured losses. The estimated hysteresis losses are about 3000 and 7500 J/cycle for the maximum currents of 2 and 4 kA, respectively.

Coupling losses were also obtained by subtracting the hysteresis losses from the total losses. As shown in Fig. 2, we found a clear difference in the coupling losses of two poloidal coil (IV-U and IV-L), even though the two coils were fabricated with exactly the same design. Time constants of the coupling losses can be estimated by using analytical expressions with a circuit model and by considering the magnetic field distribution in the coil.[1] The estimated time constants are 80 and 200 ms for the IV-L and IV-U coils, respectively. That corresponds to a 2.5-fold difference.

The experiments raise the question of why such a difference in coupling loss appears. Coupling losses are sensitive to the surface condition of strands. A copper oxide layer on a strand surface might prevent coupling currents and reduce coupling losses. The two coils have some different histories before installation in the LHD. For example, the IV-L coil fabricated earlier than the IV-U coil. In addition, only the IV-L coil was energized up to the rated point for performance demonstration before installation in the LHD. The differences in their histories might affect on the coupling currents and the coupling losses.

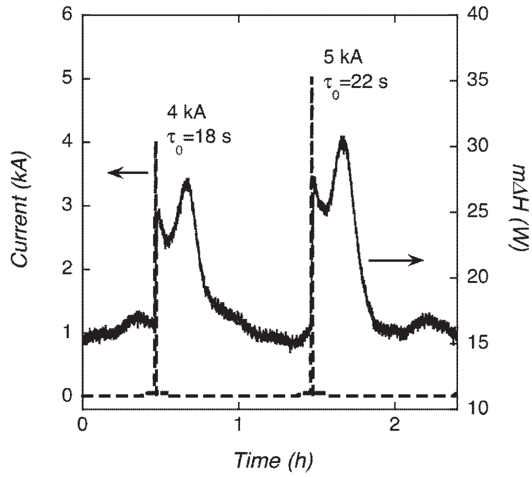

Fig. 1. Time evolution of the enthalpy and current during pulse operations for the IV-L coil.

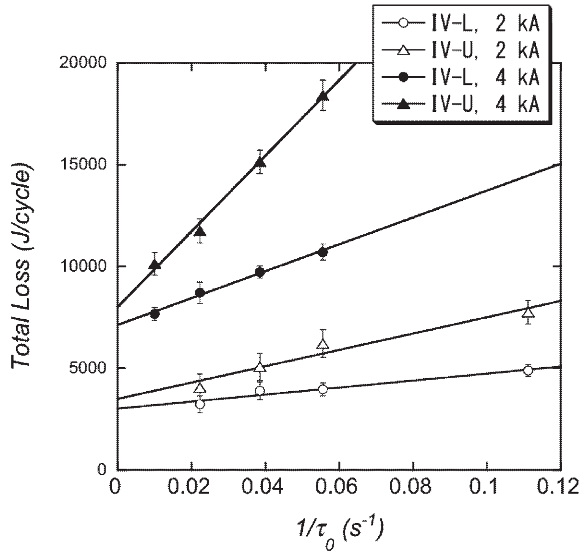

Fig. 2. Total measured losses for two poloidal coils (IV-L and IV-U). The maximum currents were fixed at 2 and 4 kA.

1) Takahata, K. : et al., Fusion Eng. Des. 65 (2003) 39