## § 20. State Estimation of Large Superconducting Coil by Highly Utilization of Voltage Signal

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In the LHD superconducting system which is composed of a number of large superconducting coils, a high-performance state estimation system of a superconducting coil is essential.

In order to obtain a reliable state estimation system, an intelligent data processing of voltage signals from the coils would be preferable. In such a situation, the authors have proposed to introduce a new estimation factor into the quench detection system. We introduced a new concept of the equivalent stored heat. And, we figured out a comprehensive decision factor of "dangerous factor" using a Fuzzy theorem.

The equivalent stored heat $W_{eff}$ is calculated by Equation (1).

$$W_{eff} = \left| \int_0^T e^{-\frac{T-t}{\tau}} \cdot vi \cdot dt \right| \qquad (1)$$

where, $T$: present time [s]
$v$: balance voltage [V]
$i$: coil current [A]
$\tau$: heat dissipation time constant [s].

In an actual calculation, we stored discretely the heat generated in a period $dt$ following Equation (2).

$$W_{eff} = \left| \left\{ \begin{array}{l} V_1 \cdot e^{-\frac{n-1}{\tau}\Delta t} + V_2 e^{-\frac{n-2}{\tau}\Delta t} + \cdots \\ \cdots + V_{n-1} e^{-\frac{1}{\tau}\Delta t} + V_n \end{array} \right\} \times I \cdot \Delta t \right| \qquad (2)$$

Where, $V_1, V_2, V_3 \cdots\cdots, V_n$ are the balance voltages at each sampling time. For the heat dissipation time constant $\tau$, we applied the value 1 [s]. And, the sampling time $\Delta t$ was selected to be 0.1 [s].

The equivalent stored heat is used as the fourth input variable for the Fuzzy system in addition to the balance voltage, the current, and the liquid helium pressure.

The balance voltage of H-I coil and the calculated dangerous rate for the data acquired in October 1998 is shown in Fig. 1 and 2, respectively. In this case, the balance voltage increased up to about 700 mV, and the coil was shut down quickly. According to our system introduced the equivalent stored heat, the dangerous rate increased to higher than 0.5 which indicates the alert level about 10 seconds earlier than the shut down.

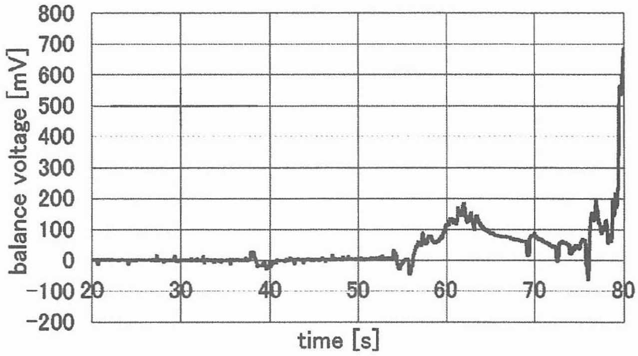


Fig. 1 Balance voltage of H-I coil in quench.

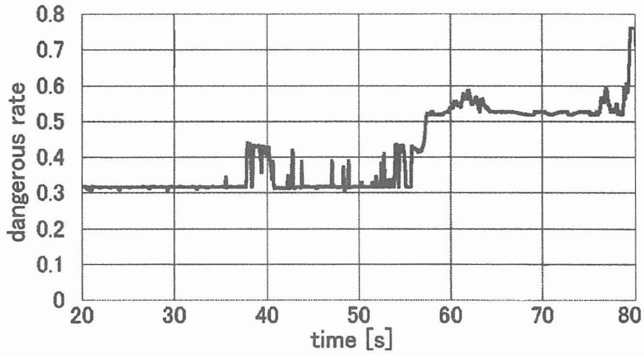


Fig. 2 Dangerous rate of H-I coil in quench.

Meanwhile, the obtained balance voltage and the calculated dangerous rate of H-I coil in case of the local normal transition are shown in Fig. 3 and 4, respectively.

As can be seen in Fig. 3 and 4, it can be recognized that the dangerous rate does not shows any change for the local normal transition.

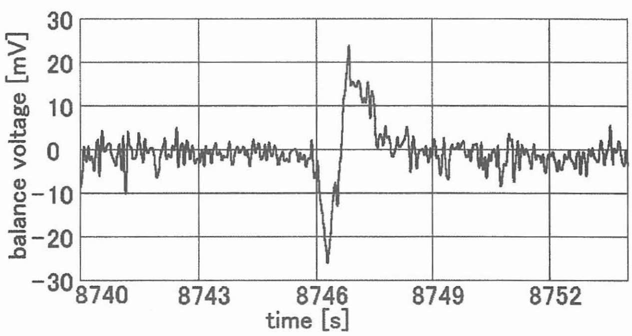


Fig. 3 Balance voltage of H-I coil in local normal transition.

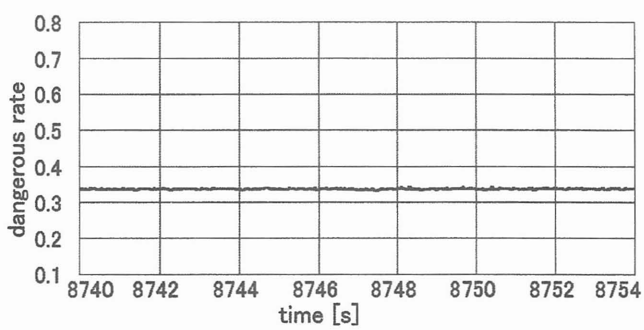


Fig. 4 Dangerous rate of H-I coil in local normal transition.