§2. Development of Monitoring and Quench Detection System of LHD Coils Using Fuzzy Theorem

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Needless to say, monitoring and quench detection for a very large superconducting magnet system is very important to protect the magnet. Particularly, in the LHD superconducting system composed of a number of large superconducting coils, a high-performance quench detection system is essential.

As well known, in LHD system, strong electromagnetic noises are induced by adjacent large superconducting coils each other. Therefore, the traditional quench detection system monitoring only voltage signal would not be sufficient. In this situation, the authors have been proposing to apply Fuzzy theorem into the quench detection system.

As told in the last year's NIFS report, in our quench detection system, Fuzzy theorem is applied incorporating the voltage signals, the coil currents, the liquid He level, and the liquid He inlet flow rate, etc.. Through a digital processing by PCs, we obtain the "dangerous rate" of the coil.

This year, we concentrated our efforts on the highly utilization of electric signals from the magnet. Targeting more precise analysis of H-I coil (Inner Helical coil), we introduced a new concept of the equivalent accumulated heat.

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

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

where,

T: present time [s]
v: balance voltage [V]
i: coil current [A]
τ: heat dissipation time constant [s].

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

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

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 τ, we applied the value 1 [s]. And, the sampling time Δt was selected to be 0.1 [s]. Meanwhile, we decided to consider the preceding heat until it decays lower than 1/100 of the initial value. So, from the condition $e^{-\frac{n-1}{\tau}\Delta t} < 0.01$, and $\Delta t = 0.1$, $\tau = 1$ [s], we obtain $n = 50$.

The calculated equivalent accumulated heat is used as an additional input variable for the Fuzzy system.

By the introduction of the equivalent accumulated heat W_{eff}, the ability of our quench detection system was improved greatly.

The dangerous rate of the H-I coil was calculated using the actual LHD data obtained November 1998.The result is shown in Figure 1.

And, for the comparison with the previous result which doesn't introduced the equivalent accumulated heat, the same data was used in the old system. The calculated result in the old system is shown in Figure 2.

As can be seen easily from these two figures, we understand that the result introduced the equivalent accumulated heat can give an alarm signal earlier than the old system.

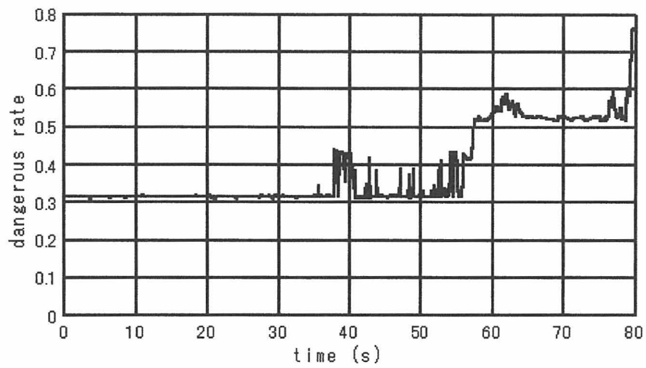

Fig. 1. Calculated dangerous rate in the new system introducing equivalent accumulated heat.

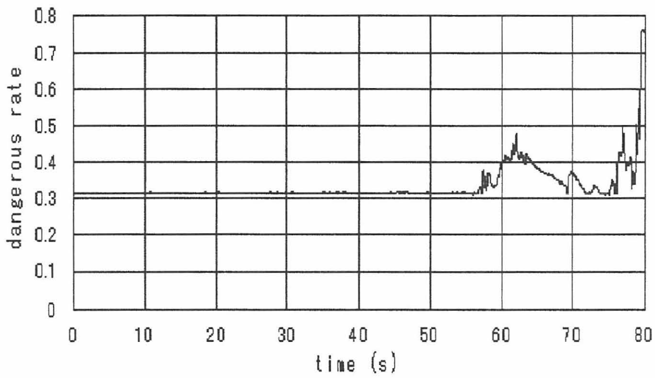

Fig. 2. Calculated dangerous rate in the old system without equivalent accumulated heat.