§4. Monitoring of the Superconducting Coil System Using Fuzzy Theorem for the Large Helical Device

Ishigohka, T., Uriu, Y., Ninomiya, A. (Seikei Univ.)
Mito, T., Imagawa, S., Yanagi, N., Sekiguchi, H.,
Yamada, S.

We have analyzed the state of the superconducting coil system of LHD at NIFS (National Institute of Fusion Science) using fuzzy theorem to detect a quench at an early stage. In this method, the "warning coefficient" of the coil system is calculated. As for the fuzzy variables, the "effective stored heat" in the coil is introduced in addition to the voltage signal in order to improve the quench detection and the state estimation. Through the experiment on the LHD coils, it was confirmed that quench alarming signals can be issued with enough leading time before a quench. On the other hand, in case of small local disturbances, the system shows only small increase of dangerous level.

The authors introduced a new variable "equivalent stored heat" in order to express the supposed temperature rise in the magnet induced by heat generation of normal conducting point. That is, the equivalent stored heat W_{eff} is given by;

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

where v is the balance voltage of the coil, i is the coil current, T is the present time, and τ is the heat dissipation time constant.

The adopted fuzzy variables are (1)the coil current, (2)the balance voltage, (3)the header pressure in the liquid He container, and 4)the equivalent stored heat.

The changes of the balance voltage, the effective stored heat, and the calculated warning coefficient during the normal propagation case are shown in Fig. 1, 2, and 3, respectively.

As shown in Fig. 1, after the balance voltage once increases up to about 0.15 V, it decreases lower than 0.05 V, and after that it increases sharply over 0.6 V. On the other hand, as shown in Fig. 2, the effective stored heat shows steady increase of the internal temperature. By introducing the equivalent stored heat, the calculated warning coefficient shows a clear stepwise increase. From these result, we can consider that the introduction of effective stored heat works considerably for the improvement of the state estimation.

From experimental resulst, we can conclude that;

(1) Introduction of fuzzy theorem is effective for the monitoring of the superconducting magnet system of the LHD,
(2) Introduction of a new fuzzy variable of "equivalent stored heat" is effective to estimate the internal temperature rise in a large superconducting magnet system typically as LHD.

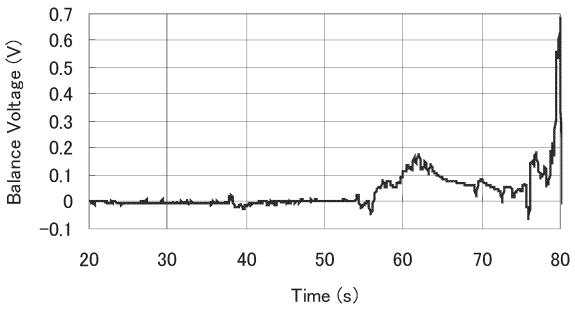

Fig. 1. Balance voltage in normal propagation.

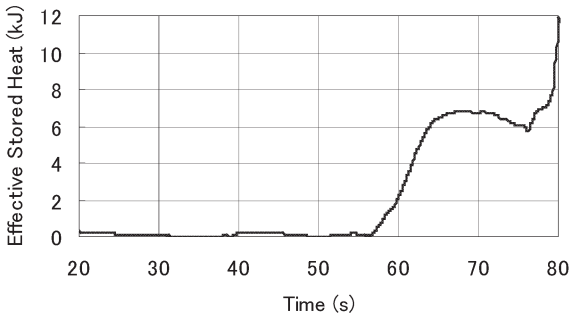

Fig. 2. Effective stored heat in normal propagation.

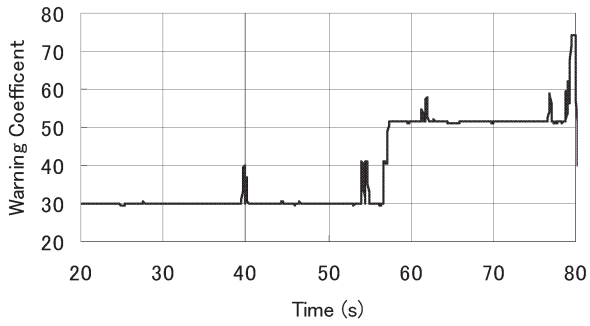

Fig. 3. Warning coefficient in normal propagation

Reference

1)Uriu. Y., Ninomiya, A., Kanda, Y., Tanabe, T., Ishigohka, T., Mito, T., and Yamada, S., "Quench Detection of Superconducting Bus-Line of LHD by Fuzzy Theorem", IEEE Transactions on Applied Superconductivity, Vol. 9, No. 2 pp.248-251, June 1999.

2)Imagawa, S., Yanagi, N., Sekiguchi, H., Mito, T., and Motojima, O., "Performance of the helical coils for the Large Helical Device in six year's operation," IEEE Transactions on Applied Superconductivity, Vol. 14, No. 2, pp.1388-1393, 2004.

3)Adachi, Y., Ninomiya, A., Uriu, Y., Ishigohka, T., Mito, T., Imagawa, S., Yanagi, N., Sekiguchi, H., Yamada, S., "Introduction of Fuzzy Logic Theorem for Quench Detection in the Superconducting Coil System of the Large Helical Device", Journal of Cryogenic Society of Japan, Vol. 40, No. 3, pp.93-99, March 2005.