§20. Thermal Behavior of a Composite Superconductor in Stability Margin Experiments

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We carried out a two-dimensional thermal analysis for the purpose of estimating the net input energy needed to cause quenching in stability margin experiments. The analysis model is based on a composite superconductor composed of Cu-sheathed NbTi/Cu with an Al stabilizer, and having a cross-section of 12.5 × 18.0 mm. The results show that the large heat capacity and low thermal conductivity of the heaters, composed of alloys and polymers, hinders thermal diffusion from the heaters to the conductor. Considering the experimental total input energy to be its stability margin may overestimate the stability of the conductor, whereas appropriate thermal analysis with experiments can be used to estimate the net input energy, which can be regarded as the real stability margin.

Fig. 1 shows the cross-section of the conductor. Its current rating is 13 kA at 7 T. Fig. 2 shows the configuration of the heater on the conductor. The heater is composed of a stainless steel tape with a polyimide surface insulation, and it is non-inductively wound around the conductor at the central bias field. In this analysis, we simplify the boundary condition in the manner that the cooling channel adjacent to the heater is considered to be the channel around the heater surface. The heat transfer coefficient is set to be 5 $kW/m^2\cdot K$ constant, because this calculation is intended to simulate the early stage of quenching. The thermal properties of each material in the mesh are set to be dependent on temperature. Under these conditions, several types of input pulse to the heater were assumed, and the temperature variations of all materials were calculated.

In order to estimate the net input energy into each material, we calculated the stored energy in each material i using

$$E_i(t) = \int_0^t M_i C_i(T_i) \frac{dT_i}{dt} dt, \tag{1}$$

where E_i is the stored energy in each material, M_i is mass, C_i is heat capacity, and T_i is the temperature of each material.

Heat transfer to liquid helium can be estimated in the same way:

$$E_h(t) = \int_0^t S h(T_p)(T_p - T_0) dt, \tag{2}$$

where E_h is energy transfer to liquid helium, S is heat transfer area, h is the heat transfer coefficient, T_P is the temperature of heater surface, T_0 is the temperature of the helium bath.

Fig. 3 shows the calculated time dependence of the energy distributions of individual materials for a pulse duration of 0.01 s, and input power of 8 W. It clearly shows that conductor materials receive less than 10% of all input energy. It also shows that since heater materials have large heat capacities and low thermal conductivities, they tend to store thermal energy in shorter pulse conditions. Fig. 4 shows the results with a pulse duration of 0.1 s, and input power of 1.5 W. In this case, energy transfer to liquid helium is considerably larger compared with the case of Fig. 3. It also shows that conductor materials receive less than 10% of all input power.

These results show that considering the experimental total input energy to be its stability margin may overestimate the stability margin of the conductor, while estimating the net input energy by thermal analysis helps to assess the real stability margin.

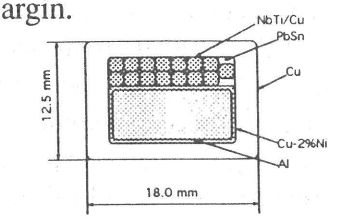

Fig.1 Cross-section of a composite superconductor.

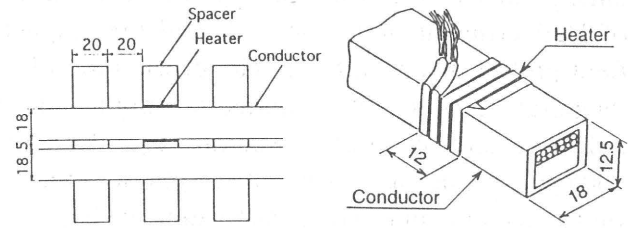

Fig.2 Configuration of the heater on the conductor.

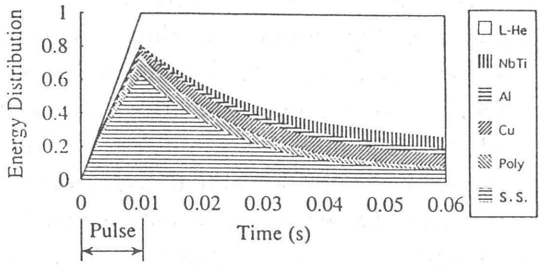

Fig. 3 The calculated time dependence of energy distributions of individual materials. Pulse duration is 0.01 s, and input power is 8 W.

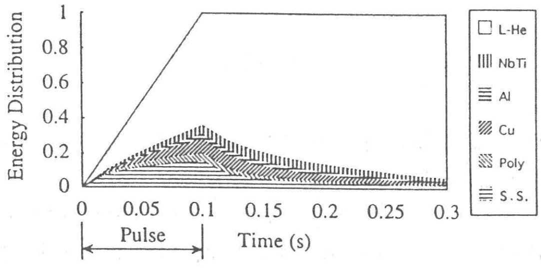

Fig. 4 The results with pulse duration 0.1 s, input power 1.5 W.