§21. Transient Analysis of Gas Cooled High-temperature Superconducting Current Leads

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The transient behavior of HTSC leads is analyzed by perturbing the temperature profile along the conductor. For examination of the stability of HTSC leads, the temperature perturbation is applied to the steady-state temperature profile. The temperature profiles along the conductor of gas-cooled HTSC leads in the steady state are obtained by solving the energy balance equations. In this work, to simplify the transient analysis of the HTSC leads, the conductor is assumed to generate Joule-heating above 77K and to be cooled by ideal heat-exchange with cooling gas. For the ideal gas cooling, the energy balance equation of the conductor of HTSC leads is generalized as,

$$\frac{d}{du}\left(\lambda\frac{dT}{du}\right)+\rho D^2-MC_gD\frac{dT}{du}=0. \quad (1)$$

Equation (1) is solved for the HTSC leads of given $D = Il/s$ with the boundary conditions of T = 4.2 and 77K at u = 0.0 and 1.0, respectively. The steady-state solution is obtained on the assumption that the evaporation induced by the heat leak from the leads supplies the cooling gas, i.e. $M = Q_c / l_h$.

Fig. 1 shows examples of temperature profiles along the conductor of D= 5.0 x 10^4 A/m obtained from the steady-state solutions of eq. (1). As shown in Fig. 1, there is the intermediate solution between the well-known upper- and lower-solutions. The domain of the normal conducting state exists in the conductor of the intermediate solution similar to that of the upper solution.

The stability of the HTSC leads is examined by the transient behavior of the temperature profile of the conductor by applying a temperature perturbation to the steady-state solution described in the previous section. Transient behavior of perturbed temperature profile is numerically analyzed by the transient heat conduction equation of the ideal gas-cooled HTSC leads given by

$$\frac{\partial}{\partial u}\left(\lambda\frac{\partial T}{\partial u}\right)+\rho D^2-MC_gD\frac{\partial T}{\partial u}=C\frac{\partial T}{\partial \tau}. \quad (2)$$

The temperature perturbation is applied to both temperature profiles of the upper- and the lower-solutions of the conductor of D = 5.0 x 10^4 A/m shown in Fig. 1. The perturbation is taken to be $\pm\sin(\pi u)$ of which maximum amplitude is 1K. Since each perturbed temperature profile recovers to the upper- and lower-solutions, respectively, the upper- and lower-solutions are confirmed be stable against the perturbation. By applying the temperature perturbation $\sin(\pi u)$, the temperature profile of the intermediate solution in Fig. 1 grows to that of the upper solution. In contrast, the perturbed temperature profile of the intermediate solution by $-\sin(\pi u)$ falls to the lower solution. If an accidental thermal disturbance raises the temperature profile of the conductor below that of the intermediate solution, the lead recovers to the state of the lower solution. Therefore, the unstable intermediate solution is regarded as a measure of the recovery criterion for the thermal disturbance. The stability of the conductor is explained by the integral S_h of the specific heat along the conductor between the intermediate- and the lower-solutions. The stability parameter S_h obtained for the ideal gas- and the conduction-cooled leads is calculated for various values of D and shown in Fig. 2 with the heat leak Q_c of the lower- and intermediate-solutions. As shown in this figure, the ideal gas-cooled leads are more stable than conduction-cooled leads.

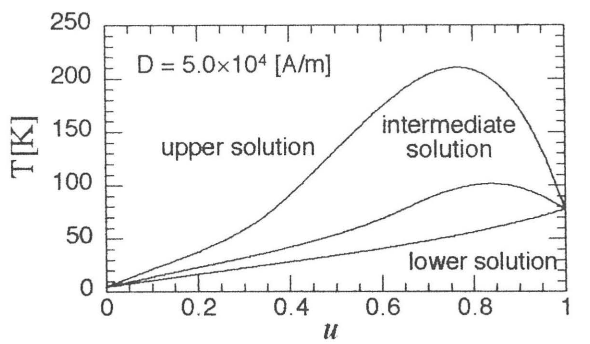

Fig. 1 Steady-state temperature profiles along the conductor of HTSC leads.

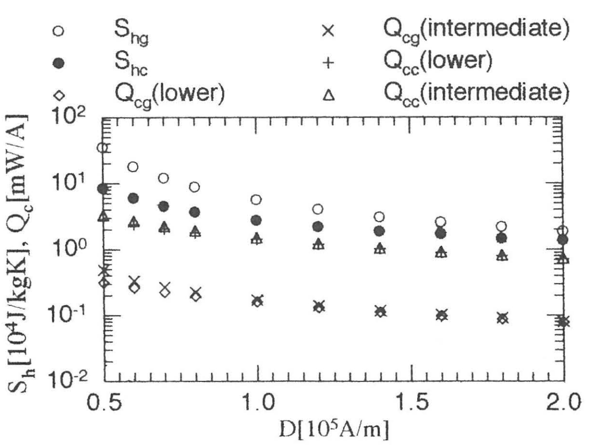

Fig. 2 S_h and Q_c as a function of D. Subscripts g and c stand for ideal gas- and conduction-cooling, respectively.