§5. Transient Heat Transfer Caused by a Stepwise Heat Input to a Flat Plate at the Middle of a Duct Containing Pressurized He II

Shiotsu, M., Hata, K., Hama, K., Shirai, Y. (Kyoto University),
Tatsumoto, H. (High Energy Accelerator Research Organization)

The transient heat transfer characteristics on a solid surface in He II produced by a large pulsewise heat input is necessary to evaluate whether a He II cooled superconducting magnet is quenched or not by an instantaneous thermal disturbance.

The purpose of this study is twofold. First is to obtain the experimental data of transient heat transfer produced by large stepwise heat inputs to a flat plate located at the middle of a duct filled with pressurized He II. Second is to clarify the effect of the duct gap on the lifetime of quasi-steady state.

Six test heater plates made of Manganin with the same dimensions of 10 mm in width, 40 mm in length and 0.1 mm in thickness were used. They located at the middle of 40-mm-wide and 100-mm-long open rectangular ducts as shown in Fig. 1. The gap lengths, *d*, from the test plates to the opposite walls for these ducts were 2, 3, 5, 10, 15 and 20 mm. Two fine 50 μm diameter platinum wires were spot welded as potential taps at around 5 mm from each end of the plate.

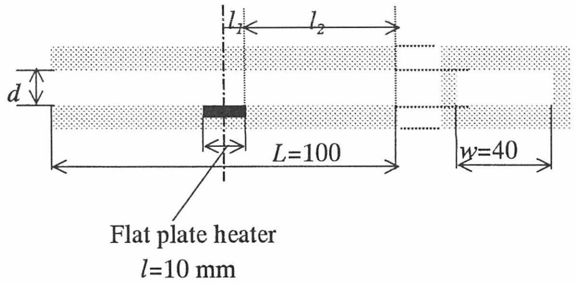

Figure 1 Schematic of a rectangular duct

Transient heat transfer coefficients for stepwise heat inputs with the heights larger than the values corresponding to the steady state critical heat flux, q_{st}, were measured for the bulk liquid temperatures of 1.8, 1.9, 2.0 and 2.1 K at atmospheric pressure. Initially, the heat input rapidly increases in time and then it takes a constant value, Q_s, after $t = t_A$. The surface temperature difference and the heat flux remain constant at ΔT_s and q_s, respectively, for a certain duration ($t_B - t_A$), then they begin to increase and decrease, respectively, at $t = t_B$. The duration $t_L = t_B - t_A$ is defined as the lifetime of the quasi-steady-state heat flux q_s.

The measured values of lifetime, t_L, are shown versus q_s with the gap length, *d*, as a parameter in Fig. 2 for bulk liquid temperature of 1.8 K. The curves for one-dimensional duct (Gorter-Mellink duct) given as follows by Shiotsu et al.[1, 2] are also shown in the figures for comparison.

$$t_L = a^{-4}\,\overline{\rho c}\,\overline{f(T)^{-1}}(T_\lambda - T_B)^2 q_s^{-4} \quad \text{for} \quad t_L \geq 1.2\ \text{ms} \qquad (1)$$

$$t_L = \overline{\rho c}\,\overline{B(T)^{-1}}(T_\lambda - T_B)^2 q_s^{-2} \quad \text{for} \quad t_L < 1.2\ \text{ms} \qquad (2)$$

where $a = 1.16$, $B(T)^{-1} = s^2 T / A^*$ and $A^* = 8000$ m^3/(kg s).

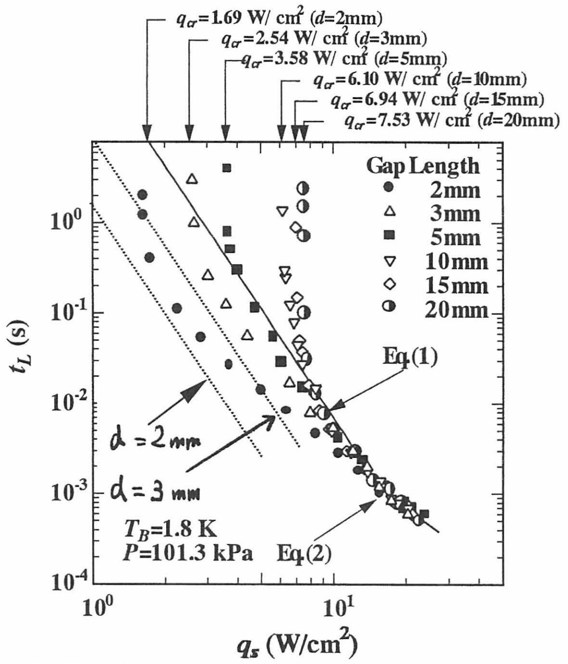

Figure 2 Lifetime versus quasi-steady heat flux for ducts with several gaps at T_B=1.8 K

The values of the lifetime for *d* larger than 10 mm rapidly decrease toward the straight line given by equation (1), reach it around t_L=20 ms, and decrease along the line and that described by equation (2).

However, for the gaps of 2 mm and 3 mm, the lifetime rapidly decreases down to below the line given by equation (1) and then approaches the line with increasing q_s. It reaches the line at t_L of around 20 ms for *d*=3 mm and 4 ms for *d*=2 mm, after that it decreases along the lines for the one-dimensional heat transfer given by equations (1) and (2).

The values of lifetime for relatively high heat fluxes are in good agreement with the curves for one-dimensional heat transfer given by Eqs.(1) and (2), independently of the gap length, and bulk liquid temperature. This is because heat transfer is very rapid and the thermal boundary layer is very thin for high heat flux range, and the heat transfer up to the λ transition would be determined within the distance from the heated surface to the opposite wall.

For relatively low heat fluxes, heat transfer up to the λ transition is slower and would be determined by the thermal phenomena occurring in a long distance from the heated surface. The effect of gap length for $d > l_1$ would be due to the heat flow expansion and that for $d < l_1$ would be due to the heat flow contraction. In the latter case, the heat transfer might be governed by the heat flux averaged over the cross sectional area of the duct, $(l_1 / d)q_s$. The following equation is given by inserting this averaged heat flux into Eq.(1) instead of q_s.

$$t_L = a^{-4}\,\overline{\rho c}\,\overline{f(T)^{-1}}(T_\lambda - T_B)^2 \{(l_1 / d)q_s\}^{-4} \qquad (1')$$

The curves of Eq. (1') for *d*=2 mm and 3mm are shown as broken lines in Figs. 3 to 5 for comparison. It appears that the curve for each gap ($d < l_1$) gives asymptotic line of the lifetime for lower heat fluxes.

References:
[1] M. Shiotsu et al., ICEC 17 (1998) 687.
[2] M. Shiotsu et al., Advances in Cryogenic Engineering, (2000) 45, 1065-1072.