§37. Transient Heat Transfer Caused by Stepwise Heat Inputs to Horizontal Wires with Various Diameters in Subcooled He II at Atmospheric Pressure

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Transient heat transfer from a horizontal wire in He II caused by pseudo-step heat inputs (rising time up to the stepheight of about 260 μs) with the heights higher than the values corresponding to the steady-state critical heat fluxes, q_{st}, was measured for the bulk liquid temperatures ranging from 1.8 to 2.1 K, and for the wire diameters of 0.08, 0.2, 0.5, and 0.7 mm at atmospheric pressure.

The transient heat transfer on each wire is such that the heat flux increases along the steady-state Kapitza conductance curve and the curve's extrapolation on the q vs. ΔT graph, and then reaches a quasi-steady-state $(\Delta T_s, q_s)$ on the extrapolated curve at time t_A. The quasi-steady state lasts for a certain duration, and then the surface temperature and heat flux 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 in Kapitza conductance regime.

The values of t_L at each value of $(q_s - q_{st})$ are longer for larger diameters wires, although the q_{st} are lower. The values of t_L are shown on t_L/r_0 versus $(q_s - q_{st})r_0^{1/3}$ graph in Fig. 1, where r_0 is the wire radius. The values of t_L/r_0 almost agree with each other and can be expressed as a single curve on this graph. To investigate the effect of the heat input waveform in its early stage, an exponential-step heat input, which increases exponentially in time ($Q = Q_0 e^{t/\tau}$) with the period τ of 0.5 ms and then keeps a constant value, was used. The results of t_L/r_0 on 0.08 mm and 0.7 mm diameter wires for the exponential-step heat inputs are also shown in the figure in comparison with the results on the same wires for the pseudo-step heat inputs. The lifetime for the exponential-step heat input decreases at a much greater rate in the higher heat flux regime. The effect of the heat input waveform in the early stage was observed significantly.

The integrated values, $(1/r_0^{2/3})\int_{t_{st}}^{t_B}(q - q_{st})dt$, obtained from each runs for the pseudo-step heat inputs to various diameter wires are shown versus $(q_s - q_{st})r_0^{1/3}$ in Fig. 2. At the time t_{st}, the increasing heat flux reaches the q_{st}, and at the time t_B, the lifetime for the value of q_s ends. The integrated values for all the experimental runs obtained for each liquid temperature are almost constant and they are independent of the step heights and of the initial waveforms during the rise time to the step heights.

The average of the integrated values for each bulk liquid temperature can be expressed by the following equation,

$$[(1/r_0^{2/3})\int_{t_{st}}^{t_B}(q - q_{st})dt]_{av.} = F(T_B)\ \mathrm{J/m^{8/3}} \qquad (1)$$

where $F(T_B) = 9.7928 \times 10^5 - 1.8620 \times 10^6 T_B + 1.1437 \times 10^6 T_B^2 - 2.2748 \times 10^5 T_B^3$ for $1.8 \le T_B \le 2.1$.

It is possible to evaluate the lifetimes due to stepwise heat inputs on various diameter wires from Eq.(1). For instance, the lifetimes for the ideal step heat inputs which cannot be realized experimentally can be estimated by the following equation,

$$\begin{aligned} t_L &= [1/(q_s - q_{st})][\textstyle\int_{t_{st}}^{t_B}(q - q_{st})dt]_{av.} \\ &= [1/(q_s - q_{st})]r_0^{2/3}F(T_B) \qquad (2) \end{aligned}$$

The curve of (t_L/r_0) versus $(q_s - q_{st})r_0^{1/3}$ for the ideal step heat inputs derived from Eq.(2) is shown in Fig. 1 in comparison with the corresponding experimental data for pseudo-step heat inputs. The values of t_L on each diameter wire for the pseudo-step heat inputs become lower than the evaluated values for the ideal step heat inputs for larger values of $(q_s - q_{st})$.

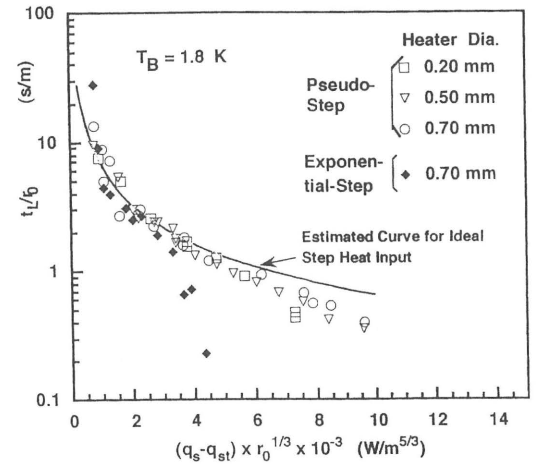

Fig.1 Relation between t_L/r_0 and $(q_s - q_{st})r_0^{1/3}$ for various diameter wires

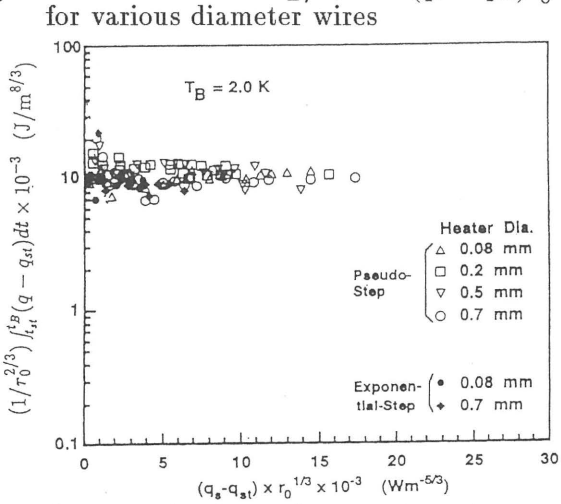

Fig.2 Integrated values of excess heat fluxes beyond q_{st} until the end of lifetime for various diameter wires