§9. Study on Turbulent Control of Supercritical Helium in Cooling Channel for Superconducting Magnet System

Okamura, T. (KEK),
Obana, T.

Superconducting magnets for high energy physics and nuclear fusion are often cooled by helium under the supercritical pressures (SHe). In order to predict various phenomena of natural convection generated in the cooling channel such as the dead end, it is important to understand not only the heat transfer characteristics but also the vortical structures and laminar-turbulent transition process with respect to SHe, however, there has been small number of studies on vortex dynamics and the transition process induced by natural convection under the SHe. In this study, we clarify the natural convection heat transfer between vertical parallel plates with several numbers of riblet in order to find the passive turbulent control method and transition processes to turbulence. Open system, $< p(\mathbf{r},t) > \simeq const$, is taken into consideration in order to avoid a complexity by the coexistence of the piston effect and thermal convection.

Fig.1 shows a half size of the three-dimensional vertical parallel heater channel with eight riblets, $\Omega_{half} := [0, L_x] \times [0, L_y] \times [0, L_z/2]$. The direction where the gravitational force acts is the negative direction of x. It is clear from experiments for the natural convection with respect to vertical heater that the laminar-turbulent transition occurs at the position, $x_c \sim (\alpha \nu D / g \beta \delta\theta)^{1/3}$. where $\delta\theta$ represents the difference between surface temperature and bath temperature of the SHe. $3.0 \times 10^9 \leq \alpha \leq 3.0 \times 10^{10}$ represents critical Rayleigh number obtained from various experiments in the case of the canonical vertical heater system with constant heated surface temperature. In order to clarify the dynamics of laminar-turbulent transition, the channel length, L_x, has to be larger than transition point, x_c. Table 1 shows the $L_x, L_y, L_z, x_1, x_2, L_3, Ra_{max}$, and number of the riblets, n. x_1 and x_2 represent the leading edge and tail end of the riblets as shown in the Fig.1.

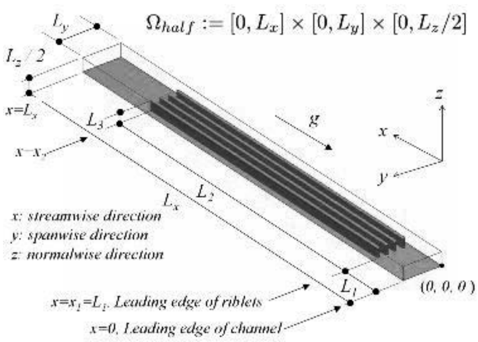

Fig.1 Half size of the three-dimensional vertical parallel plate system with long riblets.

Table 1. System Dimensions and conditions

Run-No	n (-)	L_x, L_y, L_z (m)	x_1 (m)	x_2 (m)	L_3 (m)
RUN-1	0	0.12, 0.01, 0.01	-	-	-
RUN-1'	0	0.12, 0.01, 0.01	-	-	-
RUN-2	8	0.12, 0.01, 0.01	0.01	0.02	0.004
RUN-3	16	0.12, 0.01, 0.01	0.01 0.07	0.02 0.08	0.004
RUN-4	14	0.12, 0.01, 0.01	0.01	0.10	0.004

RUN-1	RUN-1'	RUN-2	RUN-3	RUN-4
6×10^{12}	6×10^{11}	6×10^{12}	6×10^{12}	6×10^{12}

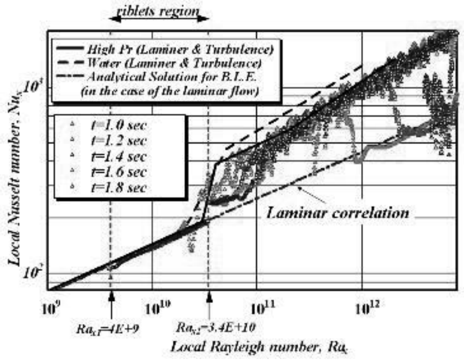

Fig.2 Relationship between Nu_x and Ra_x in the case of the RUN-2.

Fig.2 shows the relationship between local Nusselt number and local Rayleigh number from 1.0 sec to 1.8 sec in the case of the RUN-2. Heat transfer correlation in the turbulent region is obtained as $Nu_x = 0.13 Ra_x^{1/3}$.

There are two kinds of instabilities in the case of canonical vertical heater system (RUN-1). Quasi two dimensional horizontal vortex tubus are generated due to K-H instability. Next these tubes become unstable because of the frozen in motion due to non slip condition at the side wall. As a result, vortex tubes are twisted and become complicated three dimensional structures. On the contrary, horizontal vortex tubes due to the K-H instability are not generated in the case of the RUN-2 and RUN-3 with riblets. In the case, the three dimensional vortices are directly generated due to disturbance of natural convection near the leading edge of the riblets. As a result, the developed turbulent field is formed for the short time compared with RUN-1.

Relaminarization which means the "turbulent-laminar retransition" occurs in the case of the RUN-4 with long riblets. This is because entrainment and mixing effects are restricted due to the existence of long riblets. The probability to generate relaminarization strongly depends on the length, height and number of the riblets. It is clear that the several riblets give rise to not only heat transfer enhancement but also degradation such as "relaminarization". The relaminarization depends on the number, location and dimension of the riblet.