§ 21. Analysis of Cryogenic Stability in Superconducting Magnet for Nuclear Fusion Reactor by Lattice Boltzmann Method

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The nuclear fusion energy is expected as a future energy resource. In order to maintain nuclear fusion reaction, it is necessary to shut up plasma. Magnetic confinement system is the system of shutting up into the plasma container made in the strong magnetic field in order to hold the plasma of super-high temperature in a certain space and time. The important characteristics of the superconducting magnet are as followings;

The electric resistance in conductor is zero.

The power loss is small even under the large transport current.

The high density current can be transported.

It is possible to produce high magnetic field with small power.

The heating generated by the disturbances sometimes causes the normal state locally. The current at this area induces the further heating. The transition from superconducting to normal state is called "quench". It is thought that the quench is the most important problem for the superconducting magnets. Therefore, the cooling capability and the stability of the superconducting magnet have been studied by analyzing the flow of liquid helium in the superconducting magnet.

In the calculation, we applied the lattice Boltzmann method[1] which is suitable for the analysis of the complex flows and the heat transfer. And it was combined with Shen-Chen model[2] which can treat void formation. We analyzed the propagation of the normal zone in the wire together with the temperature distribution in the liquid helium, and heat transfer of the liquid helium in generation of void.

Figure 1 shows the density distribution of liquid helium using lattice Boltzmann and Shen-Chen combining model. A unity time step corresponds to 8.32×10^{-7} sec. In this figure, the heater which generates heat was set at x = 10 - 40 and y = 0. A heat disturbance at the center of the wire was applied at a time step of t = 0. Figure 2 shows the temperature distribution of liquid helium using combining model. From these figures, it could be concluded that the heat conduction of wire, the convection of liquid helium and the generation of the voids were able to analyze by the analysis method of this combined model. The temperature of liquid helium rose by the effect of the convection with increase of time steps. Since the temperature of liquid helium rose, the bubbles were generated and growing up with time steps. Because of the effect of gravity, the distribution of high-temperature region and bubble came up to the upper area step by step.

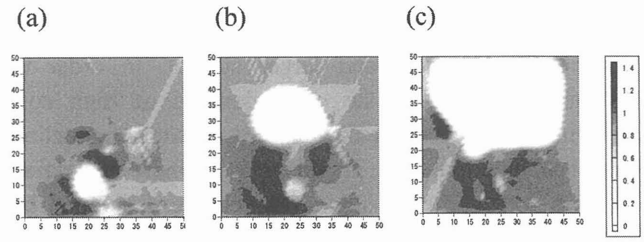

Fig. 1. Density distribution of liquid helium using combining model, (a): 3000, (b): 3500, and (c): 4500 time steps.

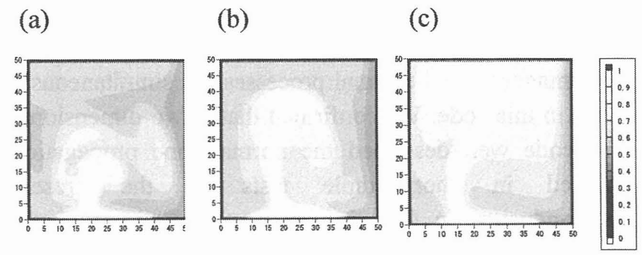

Fig. 2. Temperature distribution of liquid helium using combining model, (a): 3000, (b): 3500, and (c): 4500 time steps.

In conclusion, we could quantitatively analyze a series of instable states that occur within the superconducting magnet, such as heat conduction of wire, generation of the convection and voids after the heat generation at the wire. The stability of a superconducting wire was affected not only by the transport current but also by the flow of liquid helium.

References

1) "Introduction of Fluid Analysis by Lattice Gas Method and Lattice Boltzmann Method", Atomic Energy Society of Japan (2001).
2) Shen X. and Chen H., Phys. Rev. E, **47** (1993) 1815.