§16. Experimental Study of Cryogenic Oscillating Heat Pipes for Superconducting Magnets

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Improvement of superconducting magnets for high magnetic field, heat load and electromagnetic force is an important subject to achieve the early realization of nuclear fusion power generation. HTS (high temperature super-conducting) magnets may achieve higher magnetic fields and higher stability against a coil quench with less operation cost compared to low temperature superconducting magnets. The conduction cooling method, which is a promising candidate for a fusion magnet, can build the magnet more rigid and simplify the system and the operation

However there is a difficulty on removing heat generated in the deep portion of large scale HTS magnets operated by conduction cooling method. The thermal diffusivity of each component materials such as copper or aluminum alloy decreases as the operating temperature increases. Hence, when a part of the windings turns into the normal-conducting state, large temperature gradients are easily produced in magnets, which could cause degradation of superconducting properties and mechanical damages by excess thermal stresses.

A new method which thin cryogenic oscillating heat pipes (OHPs) are embedded into the inter-space of coil windings as heat transfer devices has been suggested in order to improve the efficiency of indirect/conduction cooling of HTS magnets[1]. OHPs are highly effective heat transfer devices which can transport several orders of magnitude greater heat flux than the heat conduction of solids and be formed in a thin plate structure.

Fig. 1 shows the schematic detail of the experimental set-up. The OHP assembly is placed in a vacuum chamber of a cryostat. The installation angle of the OHP can be changed. The pressure gauges are installed in the buffer tank and the filling pipe, which are used to control the volumetric filling ratio of the working fluid in the OHP and to monitor the pressure oscillation during the operation of the OHP. The performance of cryogenic OHPs has been intensively examined by this measurement apparatus[2][3]. The typical effective thermal conductivity has been observed to be > 10 $kWm^{-1}K^{-1}$ at 20 K. As a reference, the thermal conductivity of Cu with RRR: Residual Resistivity Ratios, = 100 at the magnetic field of 1T and 20 K is about 2,000 $Wm^{-1}K^{-1}$.

A modeling using the Karman number, the Prandtl number and the Jacob number has been attempted as the semi-empirical correlations[4]. Using a modified model and the data from cryogenic OHPs experiments, a correlation has been formulated for the heat flux in OHP, which is stated as follows:

$$q = 2.61Ka^{0.05}Pr^{0.77}Ja^{-0.97}(\exp(\beta))^{0.42} \quad (1)$$

Eq. (1) is used to fit a total of 30 data sets by means of multi-regression analysis. It is considered that this modelling with non-dimensional quantities is useful for the design of cryogenic OHPs. In Fig. 2, the resulting given by Eq. (1) and the experimental data are compared.

The cryogenic OHPs used by being imbedded in superconducting magnets as a heat transfer device has been demonstrated. The high heat transport properties of the cryogenic OHPs have been experimentally confirmed. We consider that it is possible to dramatically improve the performance of HTS magnets by using cryogenic OHPs.

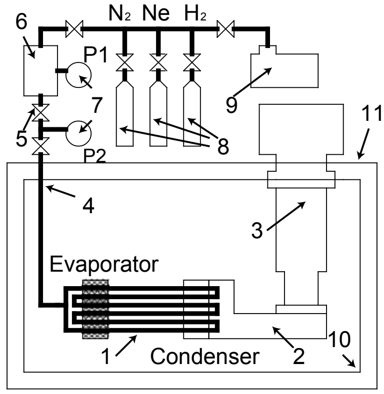

Fig. 1 Experimental set-up of a series of performance evaluation experiments of cryogenic OHPs. 1: cryogenic OHP, 2: Cu bus bar, 3: GM cryocooler, 4: filling pipe, 5: isolation valve, 6: buffer tank, 7: pressure gauges 8: gas cylinders 9: vacuum pump, 10: radiation shield, 11: cryostat.

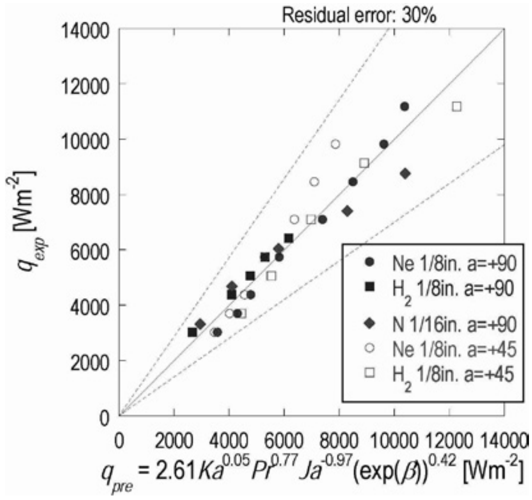

Fig. 2 Comparison of Eq. (1) with experimental results. In legends, 1/8in. and 1/16 in. indicate the outer diameter of pipes and a=+90 and a=+45 mean the inclination angle of OHP orientations from horizontal direction.

1) T. Mito, K. Natsume et al: IEEE Transactions on Applied Superconductivity **20** (2010) 2023-2026.
2) T. Mito, K. Natsume et al: IEEE Transactions on Applied Superconductivity **21** (2011) 2470-2473.
3) K. Natsume, T. Mito et al: Cryogenics **51** (2011) 309-314.
4) K. Natsume, T. Mito et al: IEEE Transactions on Applied Superconductivity (to be published)