§20. Achievement of High Heat Removal Characteristics of Superconducting Magnets with Imbedded Oscillating Heat Pipes

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Oscillating heat pipes (OHP) for cryogenic use are being developed to improve the heat removal characteristics of high-temperature superconducting (HTS) magnets. It is generally difficult to remove the heat generated in HTS windings, because the thermal diffusivities of component materials decrease with an increase of the operating temperature. Therefore, a local hot-spot can be rather easily generated in HTS magnets, and there are possibilities of observing degradation of superconducting properties and/or mechanical damages by thermal stresses. As a new cooling technology to enhance the heat removal characteristics in HTS magnets, the cryogenic OHP is proposed to be imbedded in magnet windings. The feasibility of cryogenic OHP has been confirmed by fabricating proto-types and by observing stable operations using hydrogen, neon and nitrogen as the working fluid. A high thermal conductivity was achieved that surpasses those of high-purity metals. We also propose a modified-type OHP to mitigate the orientation dependence.

The OHP has a long capillary which is bent into many turns and a working fluid with two-phase mixture is filled inside the capillary as shown in Fig. 1. The OHP is a highly efficient two-phase heat transporting device which can transport the amount of heat several orders of magnitude greater than that by thermal conduction in solid metals. In order to effectively cool HTS magnets, it is required that cryogenic OHPs can operate in a variety of installation orientations. The operating characteristics of the proto-type OHPs were examined by changing the installation orientation using the experimental setup shown in Fig. 2. The measured effective thermal conductivities are summarized in Table 1.

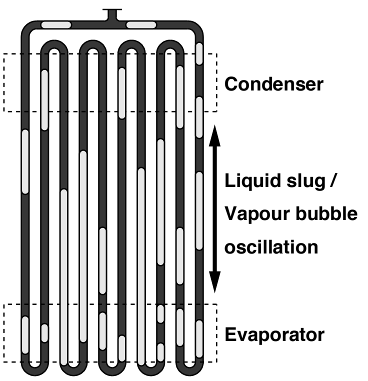

Fig. 1. Schematic illustration for showing the principle of OHP operation..

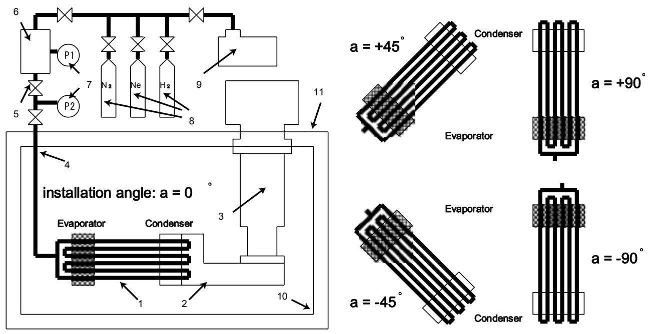

Fig. 2. Experimental setup of the proto-type cryogenic OHP for investigating the effect of installation orientation, where 1: cryogenic OHP, 2: GM cryocooler, 3: Cu bus bar connecting OHP and GM cryocooler

Table 1. Heat transport characteristics of OHP with different orientations.

Working fluid	Orientation [degree]	Liquid filling ratio [%]	Heat flux [W/mm^2]	Effective thermal conductivity [Wm^{-1}K^{-1}]
H_2	+90	50.9 – 70.0	0.03 – 0.46	8,500 – 11,480
H_2	+45	50.0 – 70.4	0.05 – 0.82	2,220 – 10,330
H_2	0	51.1 – 72.2	0.05 – 0.30	2,830 – 6,380
H_2	-45 and -90	-	-	Did not work
Ne	+90	53.2 – 75.0	0.03 – 0.46	5,100 – 19,440
Ne	+45	50.6 – 70.1	0.10 – 0.82	6,000 – 17,000
Ne	0	69.8 – 86.1	0.03 – 0.82	6,000 – 8,500
Ne	-45 and -90	-	-	Did not work

For the orientations with the evaporator located at the bottom (+90° and +45°) and for the horizontal orientation (0°), the OHP operated stably. For the orientations with the evaporator located at the top (−90° and −45°), however, the OHP did not work stably. In order to mitigate the problem of installation orientation, we propose a modified-type OHP, with both ends cooled (condenser) and the center heated (evaporator). Stable operations have been confirmed experimentally. However, the measured effective thermal conductivity was much smaller than that observed in the conventional type OHP. We consider that the effective thermal conductivity can be further improved by incorporating an optimized configuration for the OHP structure.

High heat transport properties of cryogenic OHPs have been experimentally confirmed at the operating temperature ranges of 17–30 K (for H_2), 26–39 K (for Ne) and 67–91 K (for N_2). A modified-type OHP, with both ends cooled and the center heated, mitigates the effect of installation orientation. We consider that it is possible to dramatically improve the performance of HTS magnets by using cryogenic OHPs.

1) T. Mito, K. Natsume, N. Yanagi, H. Tamura, T. Tamada, K. Shikimachi, N. Hirano, and S. Nagaya, "Achievement of High Heat Removal Characteristics of Superconducting Magnets with Imbedded Oscillating Heat Pipes," Applied Superconductivity, IEEE Transactions on, vol. 21, 2011, pp. 2470-2473.