Study of the thermosyphon cooling system with a vessel in the sea states

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Introduction

The high temperature superconductor (HTS) rotating machine has a potential application in industries and transportation systems. The HTS requires a sophisticated cooling system. We have studied the composition and its improvement of thermosyphon cooling which should be adapted to HTS rotating machine since 2006. On-board utilization of these systems requires to verify the influence of sea state on the rotor magnet operation including cryocooler. We concern that influence of a variety of sea states may affect to motion of liquid inside both condenser and evaporator with thermosyphon system. In this sense, the maximum heat load which keep stability of temperature was intensively studied on this cooling system both on-board ship and in the laboratory on the ground surface.

Experimental equipment

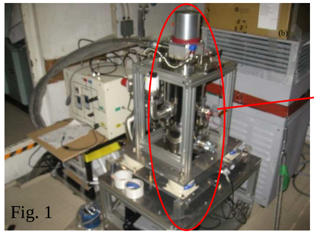

Fig. 1

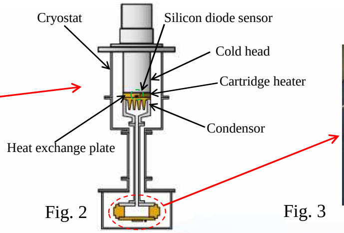

Fig. 2

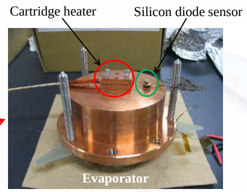

Fig. 3

Fig. 1: Experimental equipment is composed of a cryostat, a home-made closed-cycle thermosyphon, vacuum pump and a GM cryocooler. Fig. 2: The schematic view of the closed-cycle thermosyphon. Fig. 3:Both the condenser and the evaporator are together with fins optimized by thermal calculation.

The diameter of the connecting tube between them is 1/2 inch. There is a heat exchange plate between cold head of the cryocooler Cryomech AL330 and the condenser. The shape of the evaporator was cylindrical with 80 mm of inner diameter and 40 mm height. Inner surface is together with fins of 60 pieces. With liquidation of 30 NL, 35 NL and 40 NL neon gas, the liquid fulfills up to 2.4 mm, 3.5 mm and 4.6 mm in depth inside the evaporator. Heat exchange surface areas are calculated as 99 cm^2, 120 cm^2 and 142 cm^2. To clarify the thermosyphon performance comparatively, we conducted experiments both with laboratory and on-board ship using a research vessel Shioji-maru, 425 tons.

Experimental Procedure

Prior heat load application, we regulated the temperature of the heat exchange plate at 30 K. We employed two types of heat load applications on the evaporator bottom surface by using heater. Heat load application was stopped when the evaporator temperature exceeded 40 K. In this experiment, we performed the measurements with different neon quantities of 30 NL, 35 NL and 40 NL at atmospheric pressure.

1. Incremental heat load application

We applied heat load from 10 W to 70 W by 10 W and finally we added 5 W to obtain 75 W heat load application. Before applying the subsequent heat load, we waited for the stabilization of the temperatures of the evaporator and the condenser and the inner pressure.

2. Single step wise heat load application,

We applied heat load 50 W, 60 W and 70 W and finally we provided 75W. For every single step wise heat application, we removed off the preceding heat application and waited for the stabilization of all of parameters at the initial temperature 30 K.

Shioji-maru

Conclusion

On-board study with a cryogenic thermosyphon was done by using different volume of neon gas. Compared to the results carried out on the ground terrestrial, in which the condenser and evaporator are aligned vertical, the inclination coming from practical sea state provided considerable stability with suitable volume and applied step-wise heat load. The present study provides a basis toward further study on the cryogenic thermosyphon system to be applied to HTS rotating machine operated around 30-40 K with superconducting field pole and/or armature windings

Acknowledgements

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Results

1. Incremental heat load test

Fig.4 shows the results of gradual heat load test with neon 35 L in laboratory. And fig.5 shows the results of it on ship. And table1 shows the results of incremental heat load test. The evaporator temperature was successfully kept under 32 K both in laboratory and on-board ship studies. There is no remarkable contrast in case of evaporator temperatures between in laboratory and on-board ship results, which means the effect of pitching and rolling is negligible as shown in table 1.

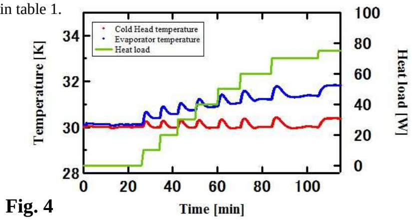

Fig. 4

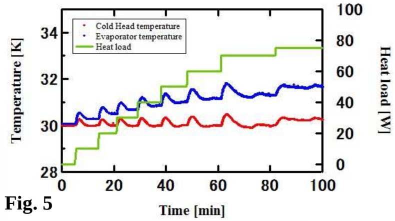

Fig. 5

Table 1. The mean temperature of evaporator when the temperature became stable after heat load application in case of incremental heat load application

Heater power [W]	Temperature [K]					
	neon 30 L		neon 35 L		neon 40 L	
	laboratory	ship	laboratory	ship	laboratory	Ship
0	30.1	30.1	30.1	30.1	30.1	30.1
10	30.4	30.3	30.4	30.3	30.4	30.3
20	30.6	30.5	30.6	30.5	30.6	30.5
30	30.7	30.7	30.8	30.7	30.7	30.7
40	30.9	30.9	30.9	30.9	30.9	30.9
50	31.0	31.0	31.1	31.0	31.0	31.0
60	31.2	31.1	31.2	31.2	31.2	31.2
70	31.4	31.3	31.4	31.3	31.4	31.3
75	32.0	31.9	31.8	31.7	31.5	31.5

2. Single step wise heat load test

Fig. 6 shows the results of single step wise heat load test with neon 35 L in laboratory. And fig. 7 shows the results of it on ship. Table 2 shows the results of single step wise heat load test. For neon gas input of 30 L and 35 L, in the terrestrial laboratory conditions, the stabilized evaporator temperatures exceed the dry out temperature under lower heat load application than that of the on-board sea states conditions. This is coming from the inclination of the thermosyphon system itself. We interpret the on-board inclination leads to enhancement of surface area of exchange heat, which may include the contribution from the 60 pieces of fin plates in the evaporator. Then, in the case of 40 L neon gas input, there is no remarkable difference in the evaporator temperatures between the terrestrial and on-board conditions. This is due to enough rich amount of liquid neon and in practice there is no effect of inclination angle

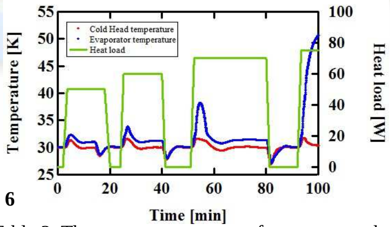

Fig. 6

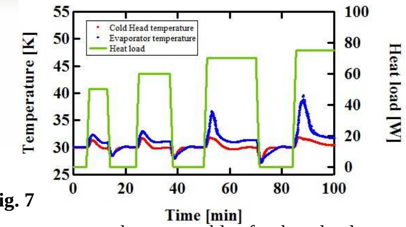

Fig. 7

Table 2. The mean temperature of evaporator when the temperature became stable after heat load application in single step wise heat load

Heater power [W]	Temperature [K]					
	neon 30 L		neon 35 L		neon 40 L	
	laboratory	ship	laboratory	ship	laboratory	ship
0	30.1	30.1	30.1	30.1	30.1	30.1
50	31.0	31.0	31.0	30.9	31.1	31.0
60	48.4	31.1	31.2	31.1	31.2	31.1
70	-	52.4	31.4	31.3	31.4	31.3
75	-	—	50.9	31.8	31.8	31.6