Performance of the Helium Circulation System on a Commercialized MEG

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Abstract. We report the performance of a helium circulation system (HCS) mounted on a MEG (Magnetoencephalography) at Nagoya University, Japan. This instrument is the first commercialized version of an HCS. The HCS collects warm helium gas at approximately 300 K and then cools it to approximately 40 K. The gas is returned to the neck tube of a Dewar of the MEG to keep it cold. It also collects helium gas in the region just above the liquid helium surface while it is still cold, re-liquefies the gas and returns it to the Dewar. A special transfer tube (TT) of approximately 3 m length was developed to allow for dual helium streams. This tube separates the HCS using a MEG to reduce magnetic noise. A refiner was incorporated to effectively collect contaminating gases by freezing them. The refiner was equipped with an electric heater to remove the frozen contaminants as gases into the air. A gas flow controller was also developed, which automatically controlled the heater and electric valves to clean up contamination. The developed TT exhibited a very low heat inflow of less than 0.1 W/m to the liquid helium, ensuring efficient operation. The insert tube diameter, which was 1.5 in. was reduced to a standard 0.5 in. size. This dimensional change enabled the HCS to mount onto any commercialized MEG without any modifications to the MEG. The HCS can increase liquid helium in the Dewar by at least 3 liters/Day using two GM cryocoolers (SRDK-415D, Sumitomo Heavy Industries, Ltd.). The noise levels were virtually the same as before this installation.

1. Introduction
Magnetoencephalography (MEG) is becoming common throughout the world and, in the near future, will probably become indispensable for measuring brain functions [1]. However, they are very expensive to run because of their cooling system. They use about 10 liters per day (l/D) of liquid helium (LHe), and commonly waste all of it by letting it escape into the atmosphere, necessitating the troublesome task of refilling the Dewar with LHe once or twice per week, which must be done by a trained technician.

The most common and efficient LHe producing system uses a Collins-type liquefier [2]. As this system uses very high pressure, it is very large and its capacity far exceeds that required for MEGs. Although a cooling system that can achieve LHe temperatures by direct cooling with a small cryocooler has been developed, it is too noisy for MEGs [3]. Other small systems that collect the evaporating helium at room temperature and return it to the Dewar after liquefaction have also been developed (e.g., TRG-350D, TaiyoNissan Co., Ltd, Tokyo; HRT-K212, Sumitomo Heavy Industries,
They cool the collected evaporated helium to about 40 K using sub-cryocoolers, then to below 4.2 K using the main cryocoolers, and then return the liquefied helium to the cryostat. However, the liquefaction requires much electricity because the evaporated helium approaches room temperature before being cooled and because the specific heat capacity of helium is relatively high. Moreover, they are also still noisy for MEGs. Therefore, at present, there is no cooling system specifically suited to MEGs.

As MEG sensor coils must be placed near to the patient’s head to detect their very weak magnetic fields, a liquid nitrogen heat shield, commonly used for Magnetic Resonance Imaging (MRI), cannot be used with MEGs. Hence, LHe is used to cool the Dewar as well as the Super Conducting Quantum Interference Devices (SQUIDs). In fact, because SQUIDs produce little heat, the LHe is mostly used for the former purpose, which is very inefficient. It would be more efficient to use relatively higher temperature helium gas (HeG) rather than LHe, to cool the Dewar [4-7].

In light of all the above serious drawbacks of the existing cooling systems, the aim of the present study was to develop an efficient small cooling system for MEGs that has a noise level low enough, does not need to have the helium frequently refilled, and is cheap to maintain.

2. Methods

The main principle of our system is to use relatively warm HeG to counter heat flowing into the Dewar from the surroundings, while using the LHe to cool the SQUID. The basic design is outlined in Figure 1. In the Dewar, the HeG near the surface of the LHe will be much colder than the HeG near the top of the Dewar. The colder HeG goes through gas flow pipe (B) to the condenser at the second cooling stage where it is liquefied, and then the LHe flows under gravity back to the Dewar through liquid flow pipe (A). The outlet of liquid flow pipe (A) is near the surface of the LHe and about 10 mm below the inlet of gas flow pipe (B). The warmer HeG, which is at about 40 K at the outlet of gas flow pipe (C), cools the Dewar as it passes through its neck. The warmed HeG is led to the first stage of the cryocoolers at a flow rate governed by a small pump and a mass flow controller (MFC). The outlet of gas flow pipe (C) is about 200 mm above the outlet of liquid flow pipe (A). Having the outlet of gas flow pipe (C) high above the LHe ensures that the temperature gradient between the outlet of gas flow pipe (C) and the LHe is relatively small, thus lowering the heat flow into the LHe. If the LHe level drops for some reason, the helium gas from a reservoir can be supplied through gas flow pipe (D).

Figure 1. Helium circulation system. A: pipe to lead LHe from condenser to Dewar, B: pipe to lead lower temperature HeG from Dewar to condenser, C: pipe to circulate higher temperature HeG, D: pipe to add pure HeG. EV: electric valve, MFC: mass flow controller.
and liquefied, which recovers LHe level.

Since the amount of helium that evaporates, and thus the amount that has to be liquefied, depends on the ambient temperature, a large capacity cryocooler is essential to cope with a wide range of ambient temperature. On the other hand, if the cryocooler liquefies too much helium, the pressure inside the system may drop, causing air to flow into the system. Therefore, our system uses two 1.5W@4.2K GM (Gifford-McMahon) cryocoolers to ensure sufficient cooling capacity and, under feedback control from the pressure in the Dewar, a 3 W heater attached to the condenser to prevent overcooling.

A transfer tube is attached to the Dewar such that a vacuum separating pipes A, B and C, which are concentric, is a continuum of the vacuum in the wall of the cold chamber. The vacuum also separates gas flow pipe (C) from the ambient air. The heat flowing from the surroundings to the LHe through the transfer tube was estimated to be lower than 0.1 W/m.

3. Experimental results

In a preliminary experimental set up used to measure the performance of the system, there was an additional heater at the bottom of an experimental Dewar which was used to measure the residual capacity of the cryocoolers to maintain the level of the LHe. The capacity was found to be 1.1 W. About 35.5 l/D of helium was evaporated from the Dewar, when the TT was not attached to the Dewar and 1.1 W of heat to the LHe was supplied. In a real situation, some more heat would be flowing from the inserted TT. Therefore, it was confirmed that at least 35.5 l/D of LHe could be re-liquefied in the experimental system. This amount is adequate for nearly all the existing MEG systems, which require about 10 l/D.

Then an experimental HCS was installed on a real MEG (Yokokawa Electric Corporation Inc. PQ1440C) in the University of Tokyo Japan. We fixed the TT to the wall of a magnetically shielded room (MSR). Figure 2 shows how the level of LHe (LL) in the Dewar changed according to the flow rate (FR) of 40 K helium gas to the neck tube of the Dewar for eight days. The LL decreased when the FR was 6 or 5 l/m during the first two days. Then, the FR was set to 10 l/m from day three and was increased stepwise to 14 l/m. The LL began to increase after the FR was set over 10 l/m at a rate of approximately 2.1 l/D on average (the diameter of the Dewar was 488 mm and 1% was roughly equal to 1 cm). The increasing rate did not change in proportion to the FR, but was stationary. Using the increase in LL in the experimental Dewar of 5.5 l/D, the helium evaporation in the Dewar of our MEG was estimated to be higher by 3.4 l/D. This increase in evaporation is natural because the MEG Dewar has 440 CH SQUIDs.

4. Installation on a commercialised MEG

The most serious problem remained to be improved was that the HCS had a TT insert tube with diameter of 3/2 inches. As all the existing MEGs have 1/2 inch insert hole to refill liquid helium, extensive redesign or deformation of the MEGs Dewar was required to use the developed HCS. Hence, we have tried to reduce the diameter of the TT insert tube to 1/2 inch to avoid the deformation. Though it was very hard to reduce the diameter of the multi-pipe TT insert tube to 1/3, we managed to achieve the goal. Once we have succeeded to develop a TT with standard insert tube diameter of 1/2 inch, there is no need to modify the MEG per see. So we could easily install the HCS on a

![Figure 2. (a) Flow rate (FR) of the 40 K helium gas was changed for 8 days, and (b) resulted in the change of liquid helium level (LL) in the dewar.](image)
As the MEG has been installed in a magnetically shielded room (MSR) about a year ago without any plan to add a HCS to it, there isn’t any proper hole to let through the TT just behind or left/right side of the MEG, which enables to use simple straight pipe TT same as used in an experimental MEG at the University of Tokyo. It was rather difficult to make a suitable hole through the existing MSR, because it requires extensive modification of the MSR. We planned to utilize the ventilation hole located upper right in the MSR, whose diameter was 170 mm. To use the hole, we designed a new TT with reduced diameter of 60.5 mm from 76.3 mm used for the experimental MEG. We also vented the TT twice to use the hole as shown in Fig. 3. The TT is tilted about 5 degrees to let the LHe flow by the gravity.

Because there was no suitable space for the cold chamber just outside the MSR in the MEG room, the cold chamber was set in a small box on a rigid concrete mount just outside of the MEG room. This positioning was also good for reducing sound noise from the cryocoolers. The compressors for the cryocoolers, which were cooled by air, were located in the other small room and the warmed air was exhausted through a window via small ducts.

HCS can increase the LHe by approximately 3 liters per day and add no extra noticeable noise in the MEG noise recording (Figure 4). As the compressors of the cryocoolers were located in another room next to the MEG room and the cryocoolers were located outside of the MEG room, there was no noticeable additional acoustic noise.

5. References
[1] Takeda T, Okamoto M, Atsuda K, Katagiri K (2008). An efficient helium circulation system with small GM cryocoolers, Cryogenics Vol. 48, pp. 6-11.
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Figure 3. HCS installed on a commercialized MEG made by Yokokawa Electric Corporation Inc. (PQ1160C). TT: transfer tube, MSR: magnetically shielded room.

Figure 4. Noise amplitude spectra of the selected 10 channels of the system, (a) before HCS installation, (b) just after HCS installation. There is no noticeable increase of noise in the (b) column.