Performance of an Efficient Helium Circulation System on a MEG

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Abstract. We report a Helium Circulation System (HCS) that re-liquefies all the evaporating helium gas, consumes far less power and has extremely lower magnetic noise compared with conventional systems. It collects warm helium gas about 300 K, cools it to about 40K and returns it to the neck tube of the Dewar to keep it cold. It also collects helium gas just above the liquid helium surface while it is still cold, re-liquefies and returns it to the Dewar. A special transfer tube (TT) about 2 m length with 7 multi-concentric pipes was developed to allow the dual helium streams. It separates the HCS with a MEG to reduce magnetic noise. A refiner to collect the contaminating gases such as oxygen and nitrogen effectively by freezing the gases is developed. It has an electric heater to remove the frozen contamination in the form of gases into the air. A gas flow controller is also developed, which automatically control the heater to cleanup the contamination. The developed TT has very low heat inflow less than 0.1W/m to the liquid helium ensuring the efficient operation. The HCS can re-liquefy up to 35.5 l/D of liquid helium from the evaporated helium gas using two 1.5W@4.2K GM cryocoolers (SRDK-415D, Sumitomo Heavy Industries, Ltd.). It has been confirmed that the HCS could be used with the real MEG system without any noise problem for over one year. The maintenance cost (electricity charges and cryocoolers maintenance fee) of the MEG has reduced to be less than 1/10 of the previous cost.

1. Introduction
Magnetoencephalographys (MEG) are becoming common throughout the world and, in the near future, will probably become indispensable for measuring brain functions. However, they are very expensive to run because of their cooling system. They use about 10 litters 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. 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. 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 LIHe 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\textsuperscript{[4-5]}.

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 Fig. 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 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 pipe A. The outlet of pipe A is near the surface of the LHe and about 10 mm below the inlet of pipe B. The warmer HeG, which is at about 40 K at the outlet of 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 pipe C is about 200 mm above the outlet of pipe A. Having the outlet of pipe C high above the LHe ensures that the temperature gradient between the outlet of 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 pipe D 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...
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. 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 the 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.

Figure 2 is a photograph of the set up that we used to test the cooling performance of the HCS installed to real MEG. We fixed the TT to the wall of a Magnetically Shielded Room (MSR).

Figure 3 shows how the level of LHe (LL) in the Dewar changed according to the flow rate (FR) of 40K helium gas to the neck tube of the Dewar for eight days. LL decreased, when FR was 6 or 5 l/m during the first two days. Then FR was set to 10 l/m from day three and was increased stepwise to 14 l/m. LL began to increase after the FR was set over 10 l/m at a rate of about 2.1 l/D on average (the diameter of the Dewar was 488 mm and 1 % was roughly equal to 1 cm). Increase rate did not change proportional to FR, but was rather stationary. As the increase of the LL in the experimental Dewar was 5.5 l/D, it was estimated the Dewar of our MEG had more helium evaporation by 3.4 l/D. It is natural, because the MEG Dewar has 44CH SQUIDs and larger volume.

Acoustic noise in the hollow of the Dewar (see figure 2) measured using a sound level meter (Yokokawa Ltd., DT-805), was 34.7 dB, while the cryocoolers were running. As there is a hole (300x250) in our MSR to allow visual image projection by a liquid crystal projector, the acoustic noise level could be lowered to 33 dB if the hole was closed. This is small enough for MEG measurements.
Just after the HCS was installed to the MEG, magnetic noise was very large with about 1 pT@1Hz and 10 pT@50Hz. As the large noise mainly came from vibration induced by the GM cryocoolers, the rigidity of the base for the GM cryocoolers was increased. Various improving methods for the electric ground were also applied and the magnetic noise at 50Hz was decreased. As shown in figure 4, the magnetic noise has been decreased to 40 fT@1Hz and 220 fT@50Hz (there was about 200fT@50Hz before HCS installation). The magnetic noise level is lower than 10 fT between 2 and 35 Hz.

4. Discussion
MEGs would be much cheaper to run if high-Tc SQUIDs, cooled by liquid nitrogen, could be used. Unfortunately, high-Tc SQUIDs are currently too noisy, so costly LHe systems must be used. Our new LHe cooling system would reduce the running cost of MEGs because almost none of the He, a rare material, is allowed to escape wastefully into the atmosphere, eliminating the hazardous task of replacing lost LHe, which requires trainings. Also, although helium itself is not a major pollutant, because our system consumes less energy, it is indirectly more environment friendly.

Though we designed our system for MEGs, our system, with its advantages, can be used for other devices in the field of cryogenics. It might even be suitable for magnetic resonance imaging (MRI): Though the reduction in running costs for MRI would not be so high, because they commonly use nitrogen thermal shields which reduces helium consumption, our system could be used to downsize the MRI Dewar because a large nitrogen container would no longer be necessary.

Our system can produce at least 35.5 l/D of LHe from the evaporated helium with two 1.5W@4.2K GM cryocoolers. The total cooling capacity of the system was estimated to be about 2.4 W by heating the condenser, because there was inevitable heat invasion at the cold chamber and the TT.

The magnetic noise level between 1 to 35 Hz is about the same with the noise level before the HCS was installed. As the noise level at 50 Hz was about 200 fT before the HCS installation, the noise level at the 50 Hz is a little bit larger. However we expect it will be reduced to the noise level before the HCS installation in the near future. Anyway, if an appropriate band pass filter or data averaging is adopted as usual, these noises have virtually no bad effect. Furthermore, if very strict measurement is required, the HCS could be stopped during measurement and the noise level is the same as that before HCS installation.

As well as being suitable for MEGs, the system is suitable for cooling Dewars in general to LHe temperatures and may even be better than conventional cooling systems used for MRIs.

5. Conclusion
We developed a new helium circulation system (HCS) for MEGs. The HCS uses two 1.5W@4.2K GM cryocoolers, and has dual helium streams; one to collect evaporated HeG immediately and return it as liquefied helium to the Dewar, and the second to use higher temperature HeG (about 40 K) to cool the Dewar. We developed a special transfer tube with seven concentric tubes to reduce the amount of heat flowing into the system. The HCS can liquefy at least 35.5 l/D of evaporated LHe. It can increase 2.1 l/D of liquid helium with our 440CH MEG system. The HCS adds virtually no acoustic and magnetic noises to the MEG.

6. References
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