8 T Cryogen Free Magnet With Variable Temperature Space

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Abstract. A conduction cooled 8 T superconducting magnetic system with variable temperature insert is developed and tested. The cryomagnetic system is based on a commercial two-stage pulse tube cryocooler with cooling power of 1W at 4.2 K. The compact superconducting magnet is manufactured from NbTi wire and impregnated with epoxy resin by “wet” technology. The clear diameter of variable temperature space is 20 mm. The system provides temperature range of 5.5-300 K. The variable temperature space is filled by low pressure helium gas. To eliminate the overheating of the magnet at high temperatures the heat switch is used in thermal coupling between variable temperature space and the 4K stage. The system design, manufacturing and test results are presented.

1. Introduction
Cryogen free superconducting magnetic systems have developed rapidly and become popular in research labs due to simple and low cost operation. GM or Pulse tube cryocooler is applied to cool down magnet without liquid helium. The most cryofree magnetic systems have room temperature bore for sample installation. This work presents design and test results of the conduction cooled 8 T superconducting magnetic system with variable temperature insert (5.5-300 K) for electrical measurements. The system is based on one Pulse Tube cryocooler. The helium gas gap heat switch is used in thermal coupling between variable temperature space and the 4K stage to avoid overheating of magnet at high temperatures of sample holder. A cryogenic heat switch is used in cryogenic systems where a thermal coupling is to be turned ON and OFF. Helium gas gap heat switches are well studied, and broadly used in spacecraft thermal control [1].

2. General description
The conduction-cooled superconducting magnet is directly connected to the 2nd stage of PT cryocooler via copper plate [2]. Thin indium foils are used to reduce thermal contact resistance. The PT cryocooler is commercial model SRP-082B from Sumitomo. The cooling capacity of two-stage PT cryocooler is 40 W at 45 K on the first stage and 1W at 4.2 K on the 4K stage.
second stage. The superconducting magnet consists of one NbTi coil which is wound directly to the technical copper former. Figure 1 shows the outside view and overall size of cryostat. The inside view of cryostat is shown on the figure 1.

![Figure 1. Outside view and overall size of cryostat.](image1)

![Figure 2. Inside view of the system.](image2)

The outline drawing of cryomagnetic system is shown on the figure 3.

![Figure 3. The outline drawing of cryomagnetic system.](image3)

The superconducting magnet together with the 2nd stage of PT cooler and heat switch are placed inside the radiation shield. Additional radiation shield is installed in magnet borehole to reduce heating from variable temperature space.
The clear diameter of variable temperature space is 20 mm. The temperature of radiation shield is estimated to be about 40 K and the sample holder could be cooled by radiation down to 50 K. Thus, two main modes of cryomagnetic system operation could be derived. For the low temperatures of the sample (<50 K) the heat switch should be ON otherwise it should be OFF. Additionally for the temperature range of sample under 15 K the variable temperature space should be filled with low pressure helium gas. The resistive heater and temperature sensor on the sample holder together with PID controller are used for temperature regulation.

The magnet current leads are composed of resistive and HTS parts. The resistive part extending from room temperature to the 1st stage of PT cooler is manufactured from brass stripes. The HTS part is made of Coated Conductor tapes (from SuperPower) and connect the magnet with resistive part. The critical current of the HTS tapes is 78 A at 77 K.

3. Superconducting magnet

The superconducting NbTi coil is wound directly to the technical copper former. The coil is fabricated with Ø 0.5 mm NbTi/Cu wire and is impregnated with epoxy resin by “wet” technology. The copper ratio of the wire is 1,0. The main parameters of magnet are shown in the table 1.

| Characteristic          | Value   |
|-------------------------|---------|
| Coil ID (clear)         | 44 mm   |
| Winding ID              | 55 mm   |
| Winding OD              | 106 mm  |
| Winding height          | 140 mm  |
| Number of turns         | 11853   |
| Max. central field at 4.2 K | 8.22 T |
| Quench current at 4.2 K | 87.8 A  |

The coil has been preliminary tested in the liquid helium cryostat. The magnet is able to generate up to 8.22 T central field. The only passive protection circuit (resistive shunt) is connected to the coil.

4. Helium gas gap heat switch

Among the different mechanisms for a heat switch to rely on, the gas gap one has the advantage of having no moving parts and simple construction. Figure 4 shows the outline drawing of the helium gas gap heat switch.

![Diagram of the helium gas gap heat switch](image)
end). The thermal conductivity of the heat switch depends on the helium pressure in gas gap between two copper tubes. It is relatively high when gas gap is filled with helium and low when gas is pumped from the switch. Thus, the thermal coupling between the variable temperature space and the 2nd stage of PT cooler could be turned ON and OFF. The heat switch could be actuated with cryopump. But in the presented cryogenic system to characterize gas gap behavior the room temperature valve on the top flange together with external pump and helium balloon are used to fill and pump the heat switch.

5. Cool down
The magnet is cooled down from room temperature to 3.6 K in 6 hours without any pre-cooling. The stationary temperature of thermal radiation shield is 31 K. The temperatures were measured by TVO sensors (calibrated by RTI). Figure 5 shows the cool down behavior of the cryomagnetic system.

![Figure 5. The cool down curve of the cryogen free magnet.](image)

6. Magnet operation
The stationary temperature of insert is 50 K when the heat switch is off and variable temperature space is pumped. Thus, two critical modes with maximal heat leakage from variable temperature space to the 2nd stage of PT cooler should be tested. The first mode corresponds to temperature of insert of 300 K. In this case the heat switch is OFF. In the second mode the heat switch is ON, variable temperature insert is filled with helium gas and temperature of insert is 50 K. Figure 6 shows temperatures of the insert and midpoint of the magnet together with charging current. The heat switch is off. The magnet was charged up to 70.8 A with ramp rate 8.4 A/min and after pause of 38 minutes the magnet current was increased up to 84 A that corresponds to magnetic field of 7.87 T. The temperature of insert was kept constant during 82.5 minutes. The stationary temperature of the magnet was 3.45 K. The increasing of insert temperature caused the heating of magnet and subsequent quench.
Additional tests revealed that magnetic system is stable at least for 3 hours at magnetic field of 7.1 T and temperature of insert equal to 300 K.

Figure 7 shows stable operation of magnetic system under critical conditions (7 T and 48 K on the sample, heat switch is on) and subsequent quench process at higher current.
The heat switch was turned on and variable temperature space was filled with helium gas. The minimal achieved temperature on the sample holder is 5.3 K. To test the magnet under critical conditions the temperature of sample holder was increased up to 48 K and magnet was charged up to 75.4 A that corresponded to 7.06 T. According to the constant temperature of magnet during 46 minutes the system is stable for the long time operation at magnetic field of 7 T and temperature of insert equal to 48 K while the heat switch is on.

The maximal magnetic field of 8.68 T with subsequent quench was achieved at 92.7 A and temperature of insert equal to 5.5 K. The temperature of magnet increases up to 43.6 K after quench and magnet can be recovered in superconducting state in 32 minutes.

7. Conclusions

The conduction cooled superconducting magnetic system with variable temperature insert for electrical measurements is developed and tested. The cryomagnetic system is based on a two-stage PT cryocooler. To eliminate the overheating of the magnet at high temperatures of the insert the heat switch is used in thermal coupling between variable temperature space and the 4K stage. The system provides temperature range of 5.5-300 K. The operating magnetic field depends on temperature range and lies in range from 7.1 to 8.2 T. The cool down time from room temperature to 3.6 K is 6 hours.

References

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