2T/5T Two-Axis Cryogen Free Superconducting Vector Magnet With Variable Temperature Space

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Abstract. A conduction cooled 2T / 5T superconducting vector magnetic system with a variable temperature space was developed and tested. The system is based on a commercial two-stage 4 K Gifford-McMahon cryocooler with the cooling power of 1.5 W at 4.2 K. The cool down time of the magnet from room temperature to 3.2 K is 17 hours. The system provides sample temperature range of 6.0-300 K. The clear diameter of variable temperature space is 39 mm. A 5 T solenoid generates magnetic field in the vertical axis and a 2 T split coil generates field in the horizontal axis. The magnets are made of niobium–titanium wire wound on a copper former. A PC controlled rotary drive is applied to rotate a sample holder around the vertical axis. Thus the measured sample can be exposed to the magnetic field in any desired direction. A helium gas gap heat switch is used as a controllable thermal link between the variable temperature space and the 2nd stage to avoid overheating of the magnet at high temperatures of the sample. The system design, manufacturing and test results are presented.

1. Introduction

Study of the angular and temperature dependence of electro-transport properties in external high magnetic field requires a special magnetic system. One of the possible ways to build such a system based on a closed cycle cryocooler and a superconducting magnet is to use a heat switch. The heat switch is a cryogenic device that allows to make or to break a thermal contact. The temperature of the NbTi magnet should be always near 4 K while the temperature of a sample varies from 6 K to 300 K. Thus the thermal link between the sample chamber and the 2nd stage of a cryocooler should be closed to reach low temperatures and opened at high temperatures of the sample.

The possibility to create a conduction cooled superconducting magnetic system with a variable temperature insert based on a single two-stage Pulse tube cryocooler and a helium actuated gas gap heat switch was experimentally shown in our previous work [1]. The helium actuated gas-gap heat switch is a reliable and simple device with no moving parts [2], [3].

The goal of this work was to design and manufacture a superconducting vector magnetic system with a variable temperature space for measurements of electro-transport properties. The PC controlled rotary drive is used to achieve any desired direction of magnetic field respectively to a sample.

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2. General description

The two-axis superconducting cryogen free magnetic system is based on a commercial Gifford-McMahon cryocooler SRDK-415 by Sumitomo [4]. Figure 1 shows the outside view of the magnetic system. Figure 2 shows the schematic representation of the cryomagnetic system.

Figure 1. Outside view of the cryostat.

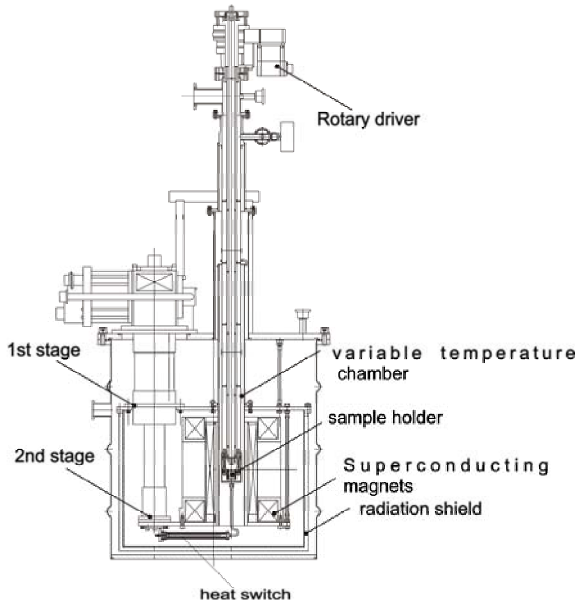

Figure2. Schematic representation of the cryomagnetic system

The superconducting magnet, the 2nd stage of the GM cooler, and the heat switch are placed inside the thermal radiation shield. An additional shield is installed in the magnet bore to reduce the heat flux from the variable temperature insert. Both thermal radiation shields are cooled by the 1st stage of the GM cryocooler.

The helium gas gap heat switch consists of two concentric copper tubes and a stainless steel housing. The internal copper tube is thermally connected to the variable temperature chamber and the external copper tube is thermally connected to the 2nd stage of the GM cooler. The thermal conductivity of the heat switch depends on the helium pressure in the gas gap between the two copper tubes. The detailed description of the heat switch integrated into magnetic system is given in [1].

To achieve low temperatures of a sample (<50 K) the heat switch should be filled with helium gas, otherwise it should be pumped. In addition, for the temperature range of a sample under 15 K the variable temperature chamber should be filled with low pressure helium gas.

The magnet current leads are composed of resistive and HTS parts. The resistive part extending from the room temperature flange to the 1st stage of a cooler is manufactured from brass stripes. The HTS part is made of Coated Conductor tapes (by SuperPower) and connects the magnet to the resistive part. The joints of the HTS part to the resistive part and the NbTi wire are thermally anchored to the 1st and the 2nd stages of the GM cooler respectively. The critical current of the HTS tapes is 110 A at 77 K.

3. Magnetic system

The superconducting magnet consists of one NbTi solenoid coil and NbTi split magnet. The split magnet consists of two coils. All coils are wound on copper formers.

Three coils are assembled on the copper plate directly connected to the 2nd stage of GM cryocooler. Additional brass studs and stainless steel cylinders are used to fix the split coils together and to increase its strength against the magnetic force. Thin indium foil is used to reduce the contact thermal resistance. Figure 3 shows a photograph of the superconducting magnet.

Figure 3. Superconducting magnet (disassembled).

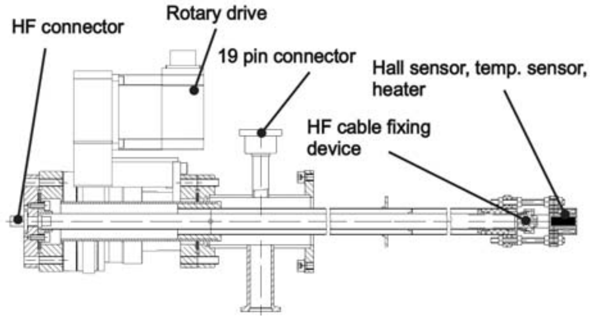

Figure4. Schematic representation of the insert

All coils are fabricated with Ø 0.6 mm (insulated) NbTi/Cu wire and are impregnated with Stycast epoxy resin. The copper to superconductor ratio of the wire is 1.3. The number of the filaments is 630. The main parameters of the magnet are shown in Table 1.

Table 1. The main parameters of the magnet

Characteristic	Solenoid	Split
Winding ID, mm	74.5	129
Winding OD, mm	107	213.9
Field inhomogeneity in 1cm Diameter Sphere Volume	<0.1 %	<0.5%
Max sweep rate	10 mT/s(0 to 3 T)	10 mT/s (0 to 1.5 T)
Combination of the magnetic field	>2 T (when split and solenoid generate equal magnetic field) >4 T (when the magnetic field generated by the split magnet is ten times less than the one generated by the solenoid)	
Operating current	89.1 A@5T	65.8A@2T
Total mass	32 kg	

4. Insert with sample holder

The insert provides measurements of electro-transport properties by means of six low frequency wires and has all necessary connections to install an additional high frequency cable (DC-60Ghz). Figure 4 shows the schematic representation of the insert.

Two coaxial thin stainless steel tubes are connected to the rotary drive (MD35-LB from the UHV Design [6]). The sample holder is mounted on the external tube and is able to rotate in the range of ±190 degrees. The static internal tube is intended for installation of the high frequency (HF) cable. The resistive heater and the temperature sensor mounted on the insert are used to control temperature together with the PID temperature controller. Three components of the magnetic field are measured by means of the commercially available 3-axis cryogenic Hall probe [6].

5. Test results

The magnet is cooled down from room temperature to 3.2 K in 17 hours without any pre-cooling and the insert is cooled down to 6 K in 18.5 hours. The temperature sensor TVO [7] is located on the copper plate which connects the split magnet and solenoid with cryocooler. The temperature measured by this sensor is marked as “Temperature of magnet”. The temperature of the insert was measured by Cernox 1050-AA-1.4L by Lakeshore [8]. Figure 6 shows the profiles of temperatures and currents in the split magnet and the solenoid during one of the tests.

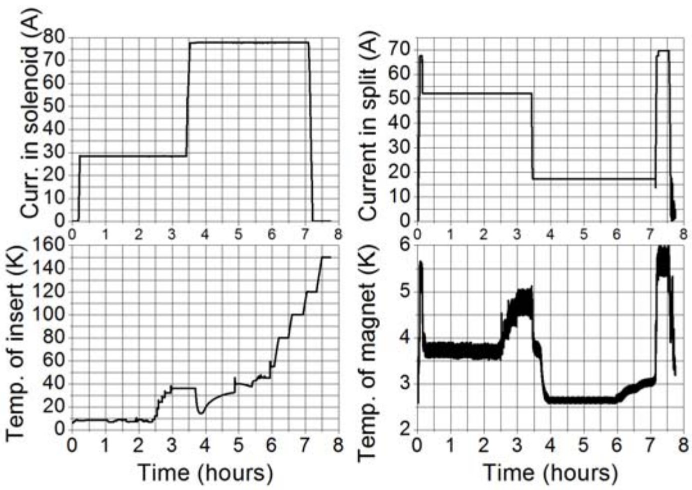

Figure 6. The profiles of temperatures and currents during the test.

The stationary temperature of the magnet was 2.7 K before the current charging. The split magnet was charged up to 67.6 A (2.05 T) with a ramp rate of 0.33 A/s (10 mT/s) and after 5 minutes its current has been decreased to 51.2 A to generate magnetic field of 1.6 T to test simultaneous operation of the split magnet and solenoid, the latter was charged up to 28.7 A (1.6 T) with a ramp rate of 0.2 A/s (11 mT/s). In this mode an overall magnetic field of 2.26 T was generated. Subsequent test shows that the whole system is able to generate 4.4 T provided the magnetic field generated by the split magnet is ten times less than the one generated by the solenoid.
During this test the temperature of insert was stabilized at various setpoints from 6 to 150 K by means of the PID controller. The heat switch was pumped at the temperature of the insert of 36 K to avoid the overheating of the magnet. The system has been tested in the whole range of temperatures of the insert (6-300 K). The typical stability of the sample holder temperature depends on the temperature range and is ±2 mK in range 6-100 K, and ±20 mK in range 100-300 K.

6. Summary

A conduction cooled 2T / 5T superconducting vector magnetic system with a variable temperature space for electro-transport properties measurements was developed and tested. The system generates designed magnetic field for the whole range of sample temperatures (6-300 K).

7. References

[1] Demikhov E I, Kostrov E A, Lysenko V V, Piskunov N A, and Troitskiy V F 2010 8 T Cryogen Free Magnet With a Variable Temperature Insert Using a Heat Switch *IEEE Trans. Appl. Supercond.* vol. 20 No. 3 612-616
[2] Bywaters R P and Griffin R A 1973 A gas-gap thermal switch for cryogenic applications *Cryogenics* vol. 13 6 344-349
[3] Donabedian M 2003 *Spacecraft Thermal Control Handbook* Vol II: Cryogenics The Aerospace Press El Segundo CA
[4] http://www.shicryogenics.com
[5] http://www.arepoc.sk/?p=30
[6] http://www.uhvdesign.com
[7] http://cryo.ru/index.php?lang=en
[8] http://www.lakeshore.com

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