A Compact Test Bed for Critical Current Evaluation on High Temperature Superconducting Tape Samples

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Background

The motivation to develop a compact test bed for critical current evaluation of HTS tape samples is from the need of verifying the critical performances of delivered HTS wires for development of HTS insert coils in our high field magnet project. For the HTS coil designers, the critical current performances at perpendicular magnetic field condition are usually taken as an top consideration. This is because the critical current in perpendicular magnetic field is the crucial parameter to determine the final performance HTS coils.

Objectives

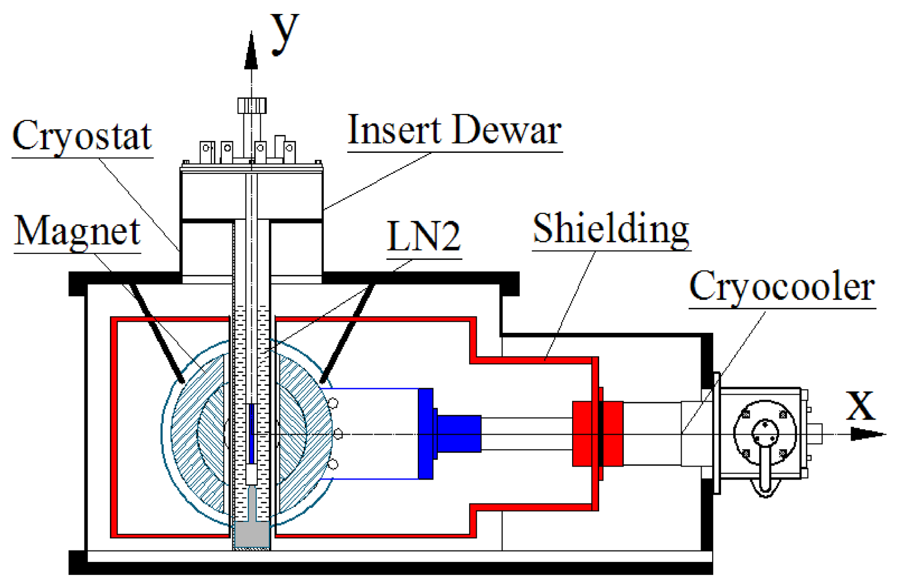
The objective of developing this compact test bed should meet requirements: (1) Easy operation and exclusive to liquid helium involvement, only liquid nitrogen used as HTS sample coolant; (2) Adjustable transverse magnetic field from zero to 3.5T, horizontal magnetic field direction ; (3) Removable sample holder, convenient to change HTS sample; (4) Batch sample tests for every cryogenic experiment; (5) Changeable angles between the tape surface and magnetic field direction; (5) Conduction cooling magnet system.

Conclusion

- A compact test bed for critical performance evaluation of HTS superconducting tape samples is designed and fabricated. It features as a conduction cooled superconducting magnet and an insert liquid nitrogen dewar, which can realize an adjustable transverse magnetic field and changeable angles between HTS tape surface and magnetic field direction.
- The conduction cooled superconducting magnet is designed as a split magnet structure, which is integrated with four coaxial NbTi coils. The central magnetic field is 3.5T when the magnet is energized with a current of 78.4A while the maximum magnetic field in the coil is close to 6T. This magnet can provide a uniform field within a cylinder volume of Ø20mm×50mm in the magnet center. The field homogeneity is better than 95%.
- The insert liquid nitrogen dewar is designed as a part of the vacuum vessel of the conduction cooled superconducting magnet. It accommodates a vertical HTS tape sample holder which can fix four HTS sample in one batch and rotate an angle ranges from zero to 90 degrees. The rotation angle resolution can be controlled to a 10-degree division every time.

Structure and Composition

The designed test bed is integrated with a superconducting magnet system and an insert dewar . The superconducting magnet system is composed with a split NbTi superconducting magnet, thermal shielding and cryostat as well as a GM cryocooler. Horizontal magnetic field is provided to HTS samples at the magnet center. The HTS sample holder is inserted to liquid nitrogen in the insert dewar.



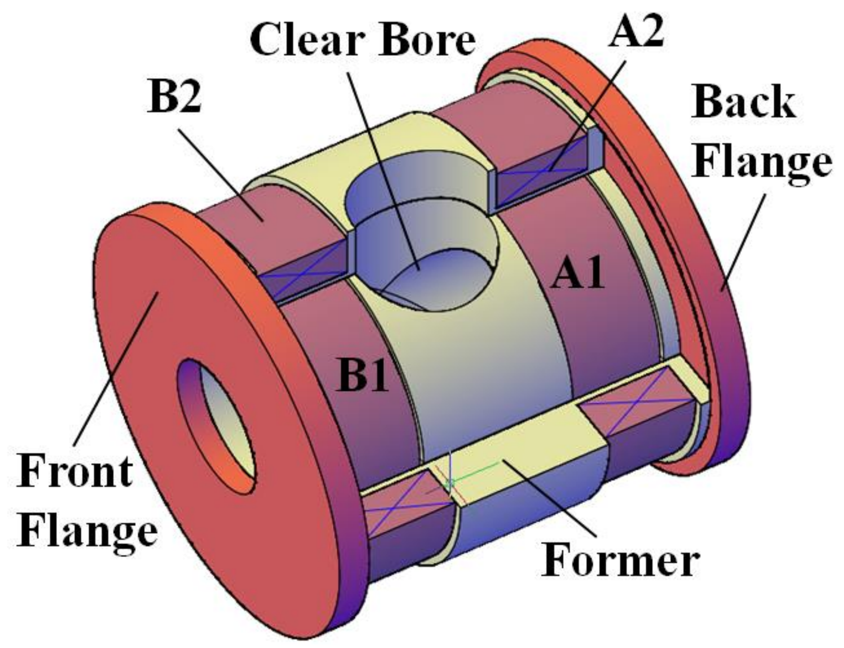
Split Superconducting Magnet

The superconducting magnet of the test bed is designed as a split coil structure. The magnet is integrated with two coaxial split NbTi coils. The split gap between coils is 90 mm. Each split coils are wound onto a Cu former. A transverse clear bore is made before the coil windings are integrated. Diameter of the clear bore is 80mm.

To improve thermal conduction between the cold head and coil windings, two flanges made from high thermal conductivity material are used to fix the split coils.

TABLE I
MAGNET PARAMETERS

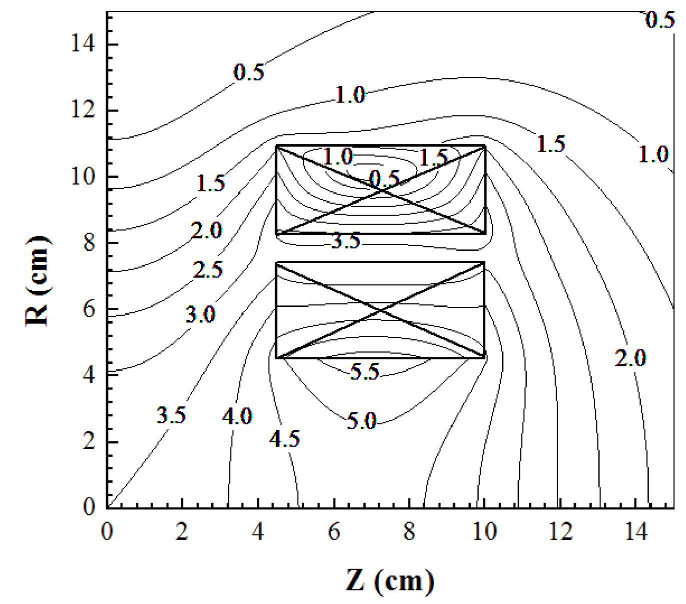
Item	Inner Dia. (mm)	Outer Dia. (mm)	Length (mm)
Magnet	80	250	248
A1	90	147	55
B1	90	147	55
A2	164	220	55
B2	164	220	55

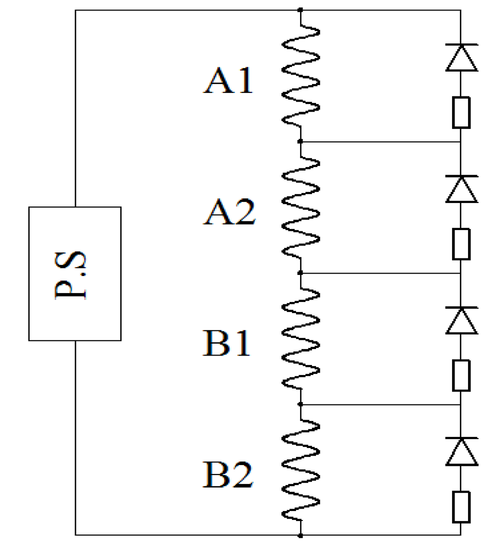


Magnetic Field and Protection

The four coils are electrically connected in series and powered by a single power supply. Total inductance of the magnet is 14.5 H. The magnet center field constant is 444.16 Gs/A. When the magnet is charged to a current of 78.8A, the horizontal magnetic field at the magnet center is 3.5 T while maximum magnetic field in the coil winding is 5.72 T.

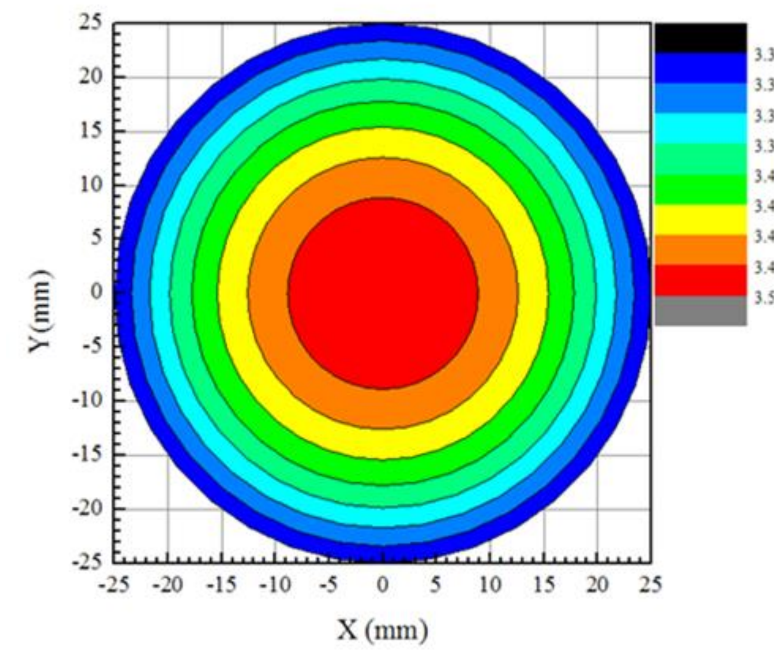
The total magnetic energy storage is 44.4kJ when the magnet is operated at the nominated current. The passive protection scheme is adopted with cold diode and resistors.

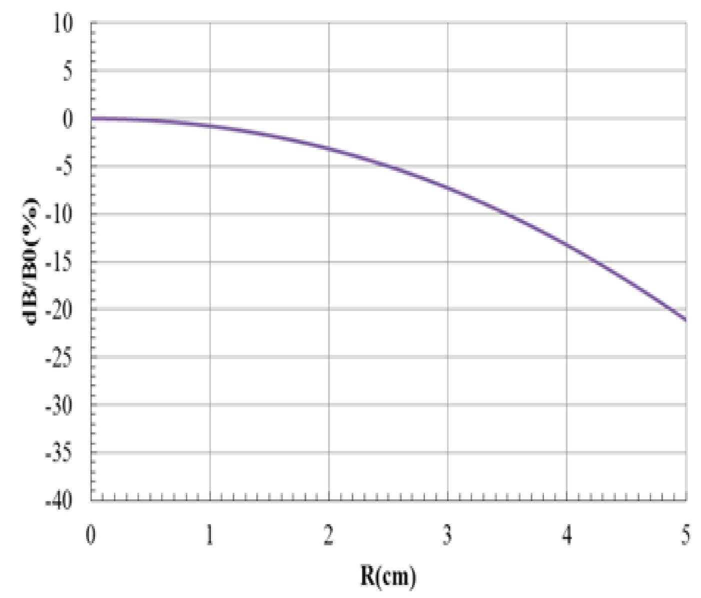




Field Quality Analysis

The magnetic field in the magnet center area is designed as applied transverse field for HTS sample test. Field mapping is performed to verify the uniformity. It shows that a field homogeneity of 95% can be met inside a cylinder volume of Ø20mm×50mm. It means that a HTS tape sample with a length of 5 cm can be suffered by a maximum perpendicular magnetic field of 3.5T, when the magnet is energized with the designed operating current of 78.8 A.





Cryogenics

Cryogenics of the test bed includes cooling of two parts: the magnet cooling and the HTS sample . The magnet is conduction cooled by a 2-stage GM cryocooler and the HTS sample is of bath cooling with liquid nitrogen. Thermal analysis is performed for the superconducting magnet system. The thermal load of first stage is 23W, including radiation from vacuum vessel, conduction from shielding support and current lead. The load of the second stage is 0.68W.

TABLE 2
TEST BED CRYOGENIC PARAMETERS

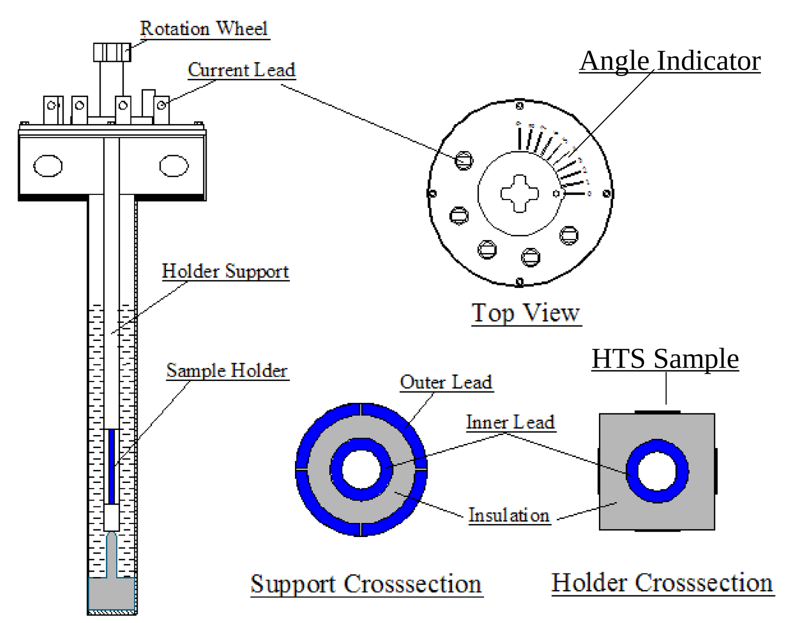
Item	Area (m^2)	Temperature (K)	Material	Status
Vacuum Vessel	1.9	300	SS304	polished
Shielding	1.22	45	Copper	Polished
Magnet	0.42	4.2	Copper	As delivered
Current Lead	12	300/45	copper	polished
Shielding Support	0.000032	300/45	FRP	machined
Magnet Support	0.000032	45/4.2	FRP	machined

Insert Dewar and Sample Holder

The insert dewar is functioned as the liquid nitrogen vessel. HTS sample holder together with a holder support bar is directly inserted to the liquid nitrogen bath.

The sample holder and its support are made as a rigid structure by integration of inner and outer current leads with FRP insulation. The inner tube is functioned as a common current lead and the four outer Cu arc splices are connected to the four HTS tape samples respectively.

The sample holder support is fixed to rotation wheel, which can be used to control the angles between magnetic field and HTS tape surface.



Magnet Test

The superconducting magnet system has been installed and tested. It takes 45 hours to cool down to a temperature of 4.4K from room temperature, driven by a GM cryocooler with a second stage cooling power of 1.4 W @4.2K. The vacuum in the cryostat is 4.7×10^{-4} Pa and the temperature on the shielding is 42K without liquid nitrogen in the insert dewar.

The magnet is charged with a power supply. One quench is happened at a current of 72A. After this training, the nominated current of 78.8A is reached, corresponding a center magnetic field of 3.5 T.

Now, the magnet system is ready for HTS sample test.

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