Power Electronics & Magnet Coil Development Division

The Power Electronics & Magnet Coil Development (*PE & MCD*) Division is a constituent of the Accelerator Technology Group of Variable Energy Cyclotron Centre, Kolkata. In the following, the major activities of this Division are reported.

Power Electronics

Power supplies of various designs and ratings have been developed in this division. These include series regulated/variac-controlled DC power supplies (up to 2 kA) with SCR pre-regulator, switching mode power supplies (SMPS), high voltage DC power supplies for RF tubes, EHT supply (Cockroft-Walton multiplier) for electrostatic deflector / inflector etc. This Division has also been catering to the specialized power supply requirements of various other institutions.

Power supplies for the radio-frequency of the superconducting cyclotron have been developed at this Division. These include anode power supply (20kV, 20A), screen-grid power supply (1.6kV, 0.5A, 60 ppm regulation), control-grid power supply (-400 to -500 V, 100mA, 100ppm), filament power supply (15.5 ±0.75V, 215 A).

Screen-grid power supply

Rectifier bank assembly foranode power supply

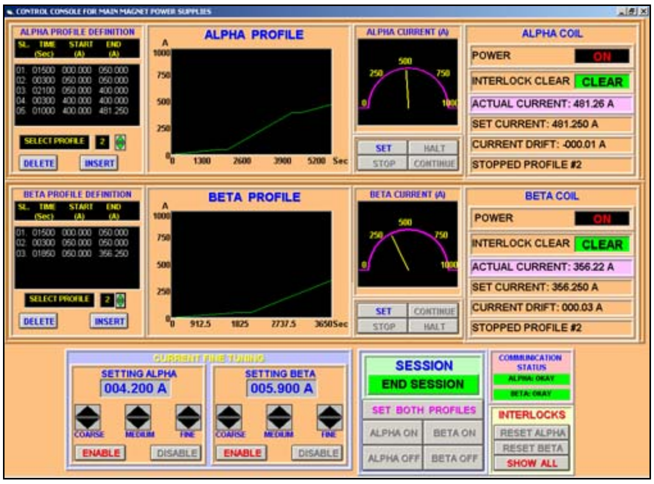
Embedded System and Supervisory Control Software Development

Microcontroller-based embedded systems – to serve as computer interface for the power supplies – are being developed at this Division. This will permit power supplies to be remotely operated over control LAN. The chief functionalities include communication interface for serial link (RS-232/ 485), 8-bit (upgradable to 16-bit) ADC readouts, up to 16-bit DAC setting, local panel LCD intetrfacing and (Boolean-type) status monitoring.

In order to operate power supplies from the control room over LAN, supervisory software with graphically-rich user interface have been developed at this Division. In particular, control software for the two power supplies of main magnet coils and for the 18 power supplies of the trim coils of the K – 500 superconducting cyclotron deserve special mention.

Coil Winding & Transformer Fabrication

In order to cater to the need of developing various magnet coils for the cyclotron and transformers for the power supplies of various magnets of the cyclotron, a Coil Winding & Transformer Cell was established at this Centre in the early 1980s. The facilities of this Cell, which is currently a part of the *PE & MCD* Division, are regularly used for fabrication of special types of transformers and inductor coils, viz. high current water-cooled transformer, high voltage resin-cast transformer, high frequency ferrite core transformer etc.



Man-Machine interface for remote operation of the main magnet power supplies

High voltage resin-cast water-cooled transformer for Final Amplifier Power Supply (FAPS) of room temperature cyclotron

When this Centre undertook the project of developing the superconducting cyclotron, a sophisticated superconducting coil winding facility was established to wind the main magnet coils of the cyclotron. This facility consists of a superconducting coil winding setup to wind up to 7 Ton weight superconducting coils with high tension, online ultrasonic flaw detection, insulation laying and checking, dimension checking of conductor etc. Cryogenic test facility was built to test and characterize superconducting cable and coils at 4.2K. This facility was used to wind the main magnet coils of the superconducting cyclotron.

Coil Winding in Progress

Completed K-500 Superconducting Coil

The basic structure of the main magnet coil of the superconducting cyclotron consists of layer-type helical winding on a stainless steel bobbin of 1473 mm (I.D.) x 1930 mm (O.D.) x 1168 mm (H). The coil was spilt into two halves (upper and lower sides of median plane) and each half was again split into large (β-coil) and short (α-coil) coils. Since the coils and conductor experiences radial and axial forces of high magnitude during energisation, the winding was done at a tension of 2,000 PSI±10% and conductors were placed one above the other with very close tolerance to restrict movement of conductor. The two α coils and β coils were finally connected in series and brought out through the lead port placed on the upper collar of the stainless steel bobbin for termination.

Cryogenic testing of SMES coil

1. Cool-down of Coil and Liquid helium filling:

The prototype small scale 0.6 MJ SMES coil with cold mass of nearly 850 kg was initially pre-cooled with liquid nitrogen and kept for thermal stabilization over few days until the coil temperature attains a temperature near 77 K. The annular space is kept under vacuum in the order of 6.0 E-6 mbar by turbo pump backed with scroll pump. Prior to cool-down by liquid helium, liquid nitrogen was taken out of SMD (Standard magnet dewar) by over pressurization with pure helium gas followed by pure helium gas purging and evacuation of the magnet chamber to roughly 20 mbar absolute. Intermediate liquid nitrogen radiation shield vessel of magnet dewar was filled with liquid nitrogen. Helium gas purging and evacuation was carried out three times and it was ensured that magnet chamber did not have any trace of liquid nitrogen. Cooling with liquid helium was carried out very slowly (~12 K/hr) in order to utilize the sensible heat of cold helium gas. Infact, we were able to utilize around 60% of sensible heat (from 4 K to 100 K) for the cool-down of the coil from roughly 100K to 4.2 K. Total liquid helium inventory used for the cool-down was ~ 170 L and liquid helium filled up to the top of magnet was nearly 100 L. Liquid helium collected for the test campaign was~ 350 L. The cool-down characteristics of the coil is as shown in figure1.

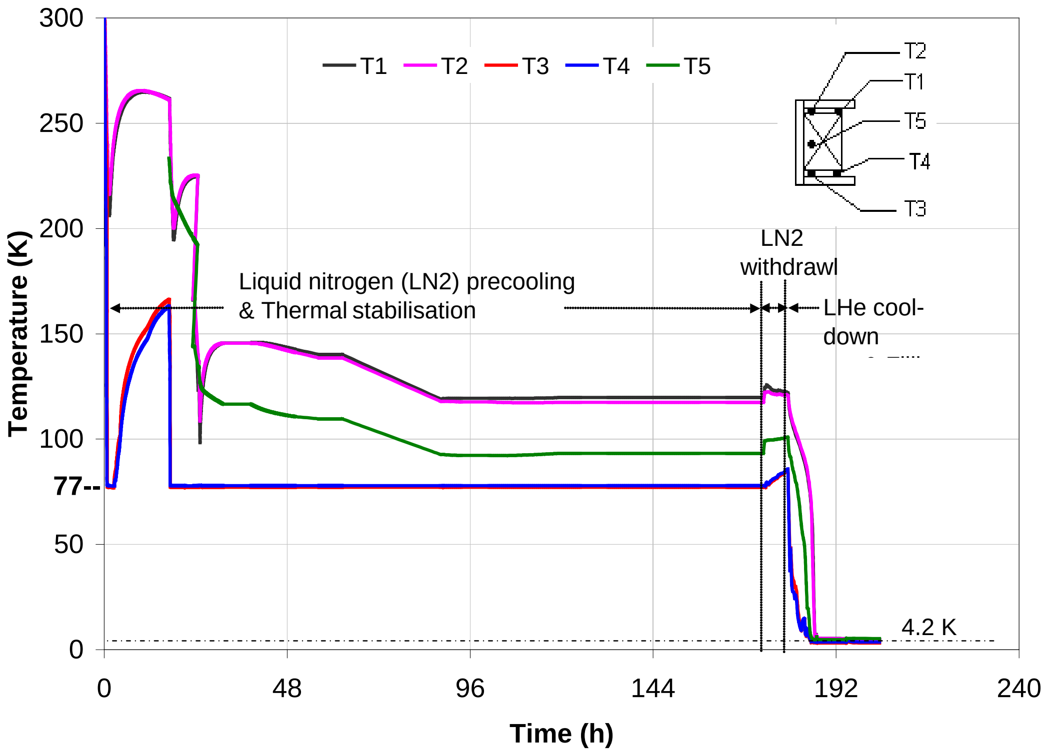


Figure1. Cool-down characteristics of the coil

2. Energisation:

After successful cool-down and liquid helium filling above the top of the coil, magnet was energized up to 560 A with central field measured 4.45 T. The measurement conforms with design calculation. The fringe magnetic field developed outside the SMD at the excitation of 560 A is ~ 0.84 kG and it was pulling the nearby iron structures, vacuum pumps, etc. towards the SMD. Therefore, we did not take any risk to increase the current level to 800 A in this test campaign without providing proper magnetic field shielding arrangement outside SMD. Magnetic field measured at the center of the coil for various excitations is as shown in figure 2 and it conforms to design data.

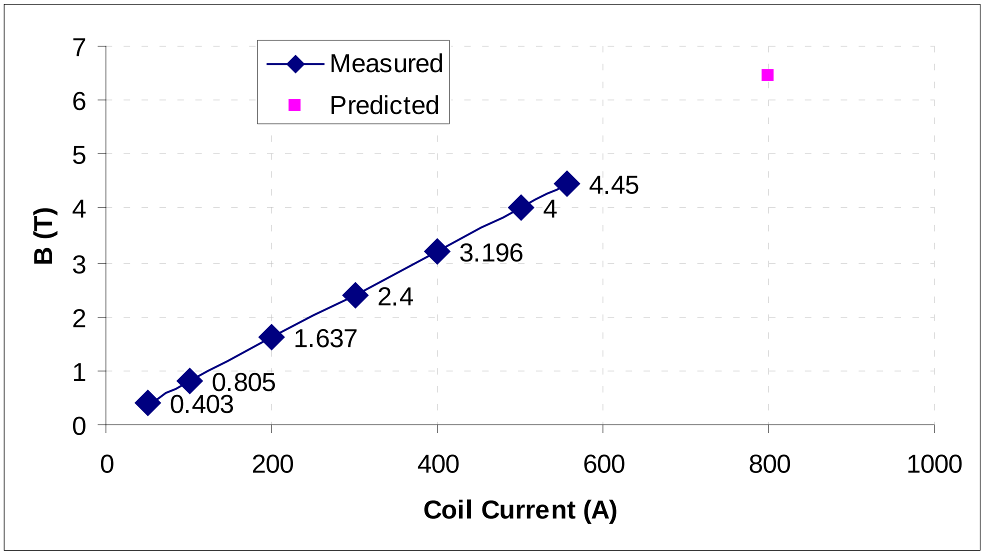


Figure2: Magnetic Field at various excitations.

While ramping up the coil with various current ramp rates, dc inductance of the coil (L) is measured as shown in figure 3 and it confirms the designed value of inductance.

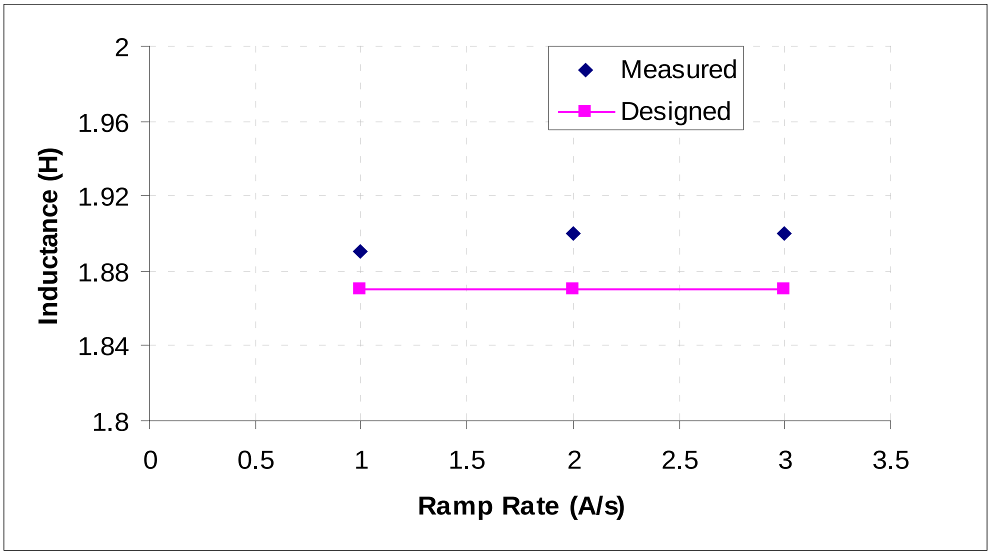


Figure3. Inductance of the coil

Boil-off helium gas with various ramping up and down rate has been measured as a function of current which gives an indication of AC loss in the coil is as shown in figure 4. Form the plot, it is very evident to observe that one should allow sufficient hold period at higher excitation levels in order to accurately predict AC loss since the helium evaporation, pressure build up in the magnet dewar, etc. are relatively slow process.

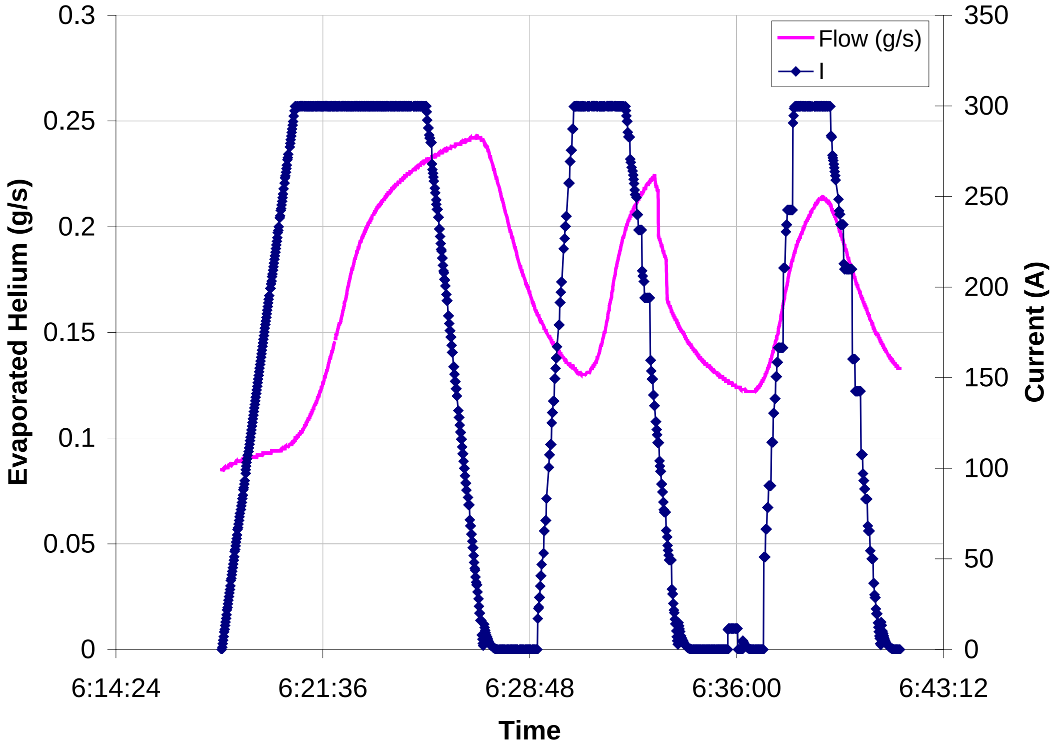


Figure4. Evaporated helium gas with excitations.

3. Test results of HTS based current lead

Liquid helium level during test
~ 200 mm below HTS part of current lead
~ 500 mm below resistive part of current lead
It is observed that HTS part of lead 2 is quenched as shown in figure 6 below possibly due to loose contact/opening of the joints between HTS tape & Cu terminal and/or degradation of HTS during soldering. The maximum temperature rise at the warm and cold ends of HTS part is about 130K and 28K respectively at ~ 300A current. Because of some problem in data acquisition system, we could not get continuous data's like rise of temperature, voltage etc. All the voltages are measured manually using multimeter. The voltage across resistive part is calculated for flow rate of 14mg/sec and its cold end temperature of 20K and is shown in figure 5 along with measurement data.

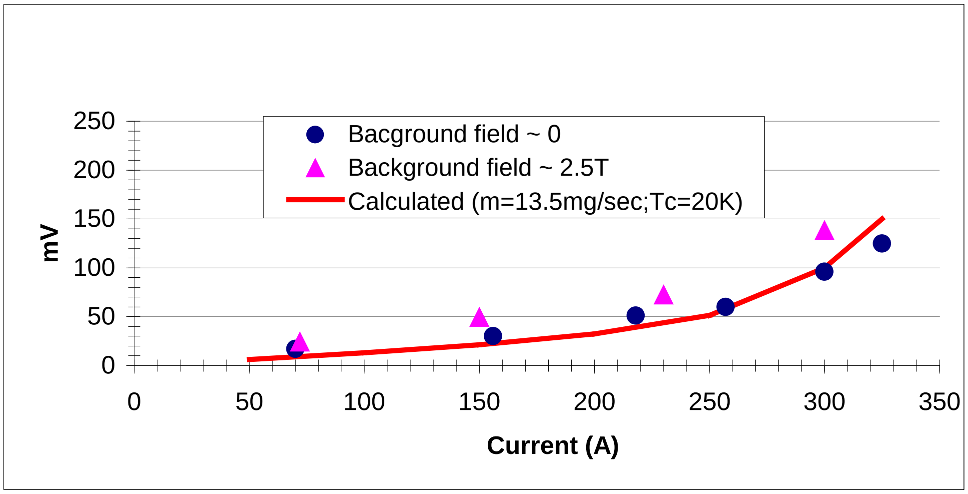


Figure 5. Voltage rise across resistive part of current lead

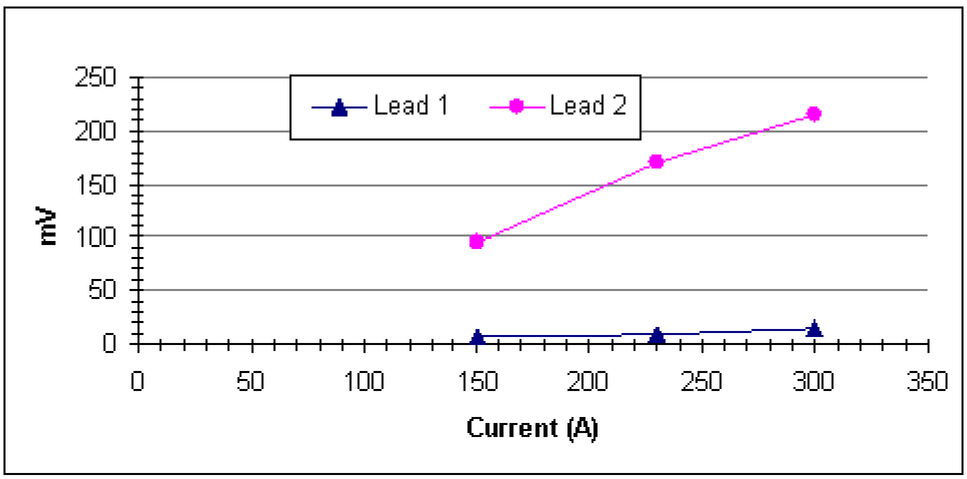


Figure 6. Voltage drop across HTS current leads in background field of 2.5 T.