

Cryogenic system for VECC K500 superconducting cyclotron

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VEC Centre, Kolkata in India is at an advanced stage of commissioning a K500 superconducting cyclotron. The superconducting coil of the magnet for cyclotron is cooled by liquid helium. Three liquid helium cooled cryopanel, placed inside the Dees of the radiofrequency system, maintain the vacuum in the acceleration region of the superconducting cyclotron. The cryogenic system for magnet for cyclotron has been tested by cooling the coil and energizing the magnet. The cryogenic system for cryopanel has also been tested. Heater and temperature sensor were placed on the liquid helium cold head for cryopanel. The temperature of the cold head was observed to be below 20 K upto a heat load of 11.7 watt.

INTRODUCTION

VECC superconducting cyclotron [1] uses liquid helium and liquid nitrogen for cooling the superconducting cyclotron magnet and the cryopanel. The cryogen delivery system for transferring liquid helium and liquid nitrogen from the helium refrigerator and liquid nitrogen storage tanks to the superconducting cyclotron was constructed in two phases. The cryogen delivery system for cyclotron magnet was constructed initially and, thereafter, cryogen delivery system for cryopanel was constructed.

After completion of iron magnet assembly, cyclotron magnet cryostat assembly and assembly of the cryogen delivery system for magnet, the coil was cooled to 4.5 K. The coil was immersed in liquid helium in the cyclotron magnet cryostat. The magnet was energized to different current levels and magnetic field mapping of the superconducting cyclotron magnet was completed. The installation and commissioning work related to extension of cryogen delivery system to supply liquid helium and liquid nitrogen to the cryopanel was then taken up. Fabrication, inspection, testing and installation of all individual lines and valve boxes were completed according to predetermined quality assurance plan. In order to simplify testing, the cold heads were enclosed in vacuum enclosures and the enclosures were evacuated. Temperature sensors were put on one of the helium and nitrogen cold heads. Cool down of the helium system was started. After filling the pump sump with liquid helium, the pump was operated. The desired cooling was also not observed at the cold head of the cryopanel even after prolonged operation. Different options were examined for improving cooling at the cold head of the cryopanel. After carrying out some modifications in the helium circuit, the cold heads were cooled successfully to 4.5 K. This paper describes the cryogenic system for the magnet and cryopanel for superconducting cyclotron and the test results of commissioning the system.

CRYOGENIC SYSTEM FOR VECC SUPERCONDUCTING CYCLOTRON

The 4.5 K refrigeration requirement of the VECC superconducting cyclotron is met by a helium liquefier/refrigerator, Helial 50, procured from Air Liquide, France. Without liquid nitrogen precooling, the helium refrigerator/liquefier has a liquefaction capacity of 50 litres/hour and when operated as a refrigerator, it has a capacity of 160 watt at 4.5 K. The liquid helium produced in the refrigerator is stored in a 1000 litre liquid helium dewar. From the dewar, liquid helium is supplied to the superconducting cyclotron. During cool down of the cyclotron magnet, cold helium gas from the refrigerator is used. A simplified P&I diagram for the liquid helium system of superconducting cyclotron is given in Figure 1.

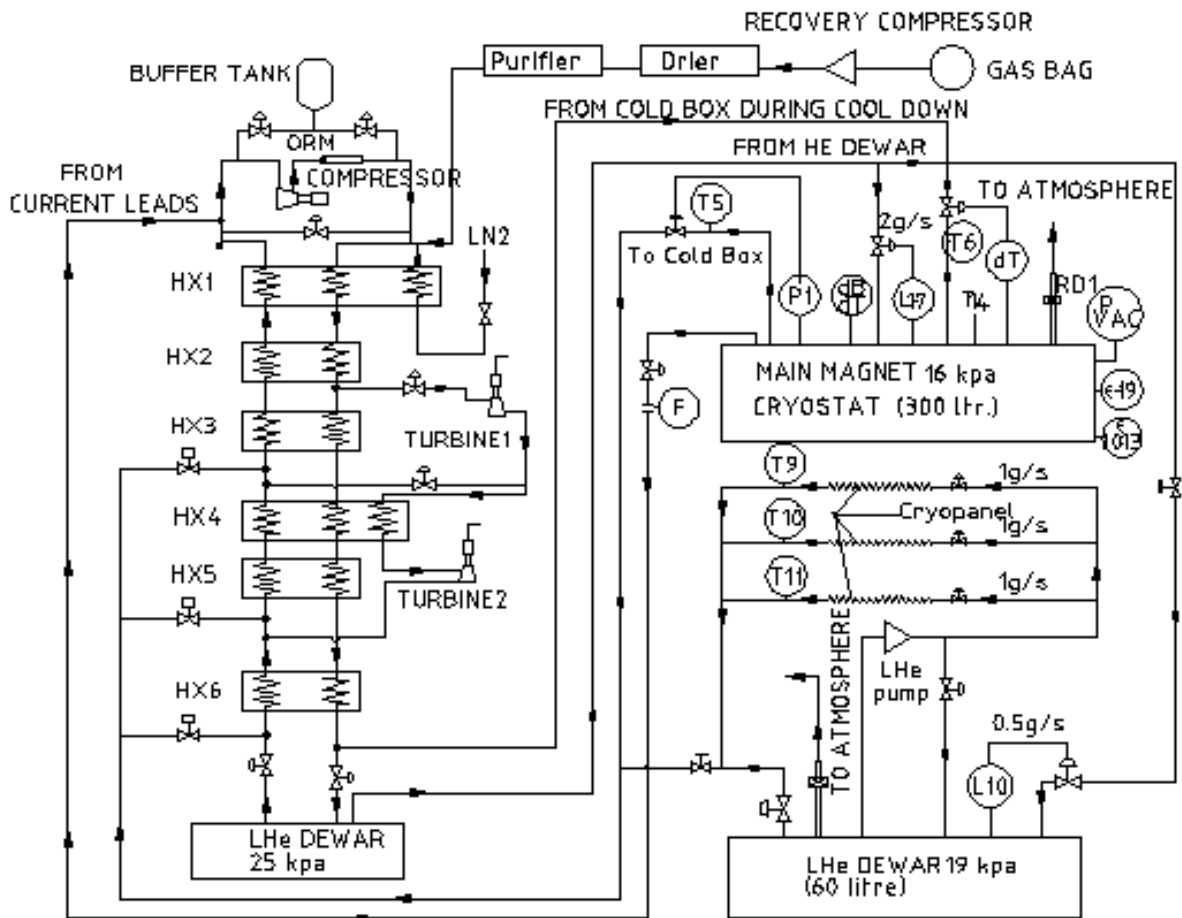


Figure 1 Simplified P&I diagram for liquid helium system of superconducting cyclotron

A liquid nitrogen shielded cryogenic transfer line carrying liquid helium, return helium gas, liquid nitrogen, return liquid nitrogen passes through all the floors of the building. Vacuum insulated cryogenic transfer lines carry liquid helium and liquid nitrogen from the helium liquefier, liquid helium dewar and liquid nitrogen dewar to this liquid nitrogen shielded line. Vacuum insulated cryogenic transfer lines carry liquid helium and liquid nitrogen to the cyclotron magnet. Liquid helium flows to the superconducting

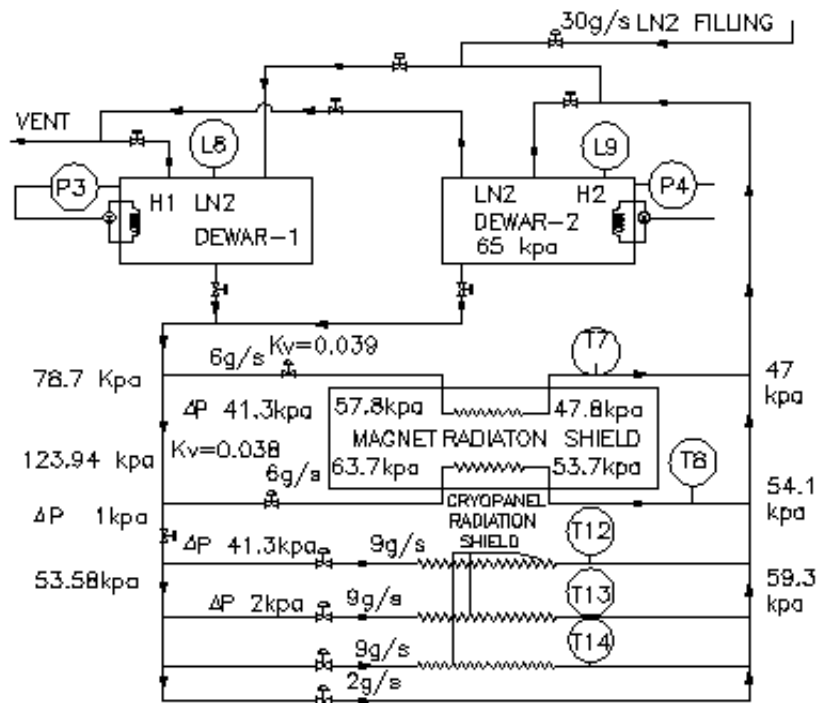


Figure 2 P&I diagram for the liquid nitrogen system of superconducting cyclotron

cyclotron by gravity. A liquid helium pump ensures the required flow of liquid helium through the cryopanel. The basement manifold contains distribution valves and the liquid helium pump.

In the VECC superconducting cyclotron, liquid nitrogen is used to cool the thermal shield of the liquid helium cooled cyclotron magnet and cryopanel. Liquid nitrogen is procured from outside agencies, stored in storage tanks outside the building and supplied to two dewars placed in the superconducting cyclotron building. The P&I diagram of the liquid nitrogen system is given in Figure 2. Liquid nitrogen for the cyclotron magnet is supplied from two liquid nitrogen dewars placed at highbay. They are filled up from dewars placed outside the building. One of the dewars is in filling mode. This dewar receives liquid nitrogen from a storage dewar located at ground floor. It also receives the return liquid nitrogen from the cyclotron. When the level of liquid nitrogen rises and reaches the preset high level, the dewar is isolated and pressurized using a pressuriser. The other dewar is in delivery mode. This dewar discharges liquid nitrogen to cool the thermal shield of cyclotron magnet and cryopanel. Once the level of liquid reaches the preset low level, the vent valve connected to this dewar is opened. Flow of liquid nitrogen is initiated from the other dewar. Pressure of liquid nitrogen in the dewar is adequate for flow of liquid nitrogen through the thermal shield of the superconducting magnet and cryopanel.

PROCESS AND INSTRUMENTATION DESIGN

The simplified process and instrumentation diagram of liquid helium and liquid nitrogen system for superconducting cyclotron [2] is given in Figures 1 and 2. The mass flow rate and pressure drop in different segments is indicated in the Figures. In order to ensure the designed flow rates, the liquid nitrogen dewars are operated at a pressure of 65 kPa. The liquid helium flow rates were calculated based on a heat load of 60 watt at 4.5 K in the cyclotron magnet cryostat and 20 watt at 4.5K for each cryopanel. Figure 3 gives the head loss characteristics for the helium system for cryopanel. A helium pump for 8 g/s and 25 kPa head was selected to provide the required flow in the system.

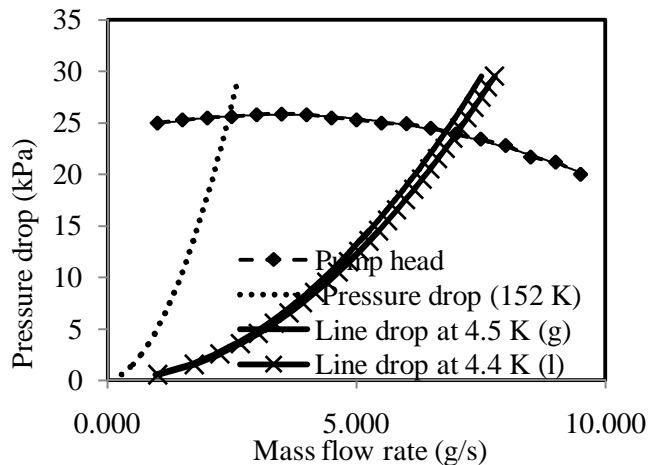


Figure 3 Head-loss characteristics for helium cryopanel system

The temperature of coil, strain in the coil, and inlet and outlet helium temperature are monitored during cool-down of the cyclotron magnet. In order to maintain the stress in the coil within safe limits, the temperature difference between the inlet and outlet helium gas is kept below 100 K and coil temperature differential is maintained below 50 K. Strain on nine support links are monitored for coil centering. Liquid helium level sensors are located at seven locations to cover the complete cyclotron magnet cryostat. The lower and upper half of the cryostat have two sensors to provide redundancy. One sensor is placed in the lead port, refrigeration port and safety port. Signal from the level sensor placed in upper half is used to keep the coil completely submerged in liquid helium while the cyclotron magnet is energized. Helium pressure

in the cyclotron magnet cryostat is monitored and maintained at a constant level for proper operation of the helium circuit. Helium gas flow through the current leads is controlled to keep the voltage drop across the current leads within safe limits.

The helium return temperature from the cryopanel is monitored to ensure that temperatures of the cryopanel are below 20 K. Helium level and pressure in the liquid helium pump sump are maintained at constant level for proper operation of the liquid helium circuit for cryopanel. Outlet pressure of the liquid helium pump and vacuum of the annulus for cyclotron magnet cryostat and manifolds are monitored.

Pressure and level of the liquid nitrogen dewars, current through heaters in the pressurisers, temperature of the heater, outlet temperature of liquid nitrogen from different branches, are used for controlling flow through the different branches of the liquid nitrogen circuit.

CONTROL SYSTEM

The operation of the helium refrigerator is controlled by a PLC. The cryogen delivery system is operated using another dedicated PLC. The parameters of cyclotron magnet and cryogen delivery system are continuously monitored by this PLC to control the flow of liquid helium and liquid nitrogen through the system [3]. The position of on-off valves and pressuriser currents in the liquid nitrogen system, opening of control valves in the liquid helium system are changed. It monitors the helium flow through the current leads, condition of helium liquefier, voltage drop across coil, lead voltage drop, vacuum in cryostat, oxygen concentration in the building to generate alarm and safety interlocks. The control software has facility for remotely displaying the parameters of the system and controlling it.

CONSTRUCTION OF THE CRYOGEN DELIVERY SYSTEM

Construction of the cryogen delivery system for superconducting cyclotron was carried out in two phases. After completing the process design, components for the cryogen delivery system for cyclotron magnet were designed as per ASME Boiler and Pressure Vessel Code, Section VIII [4]. Inspection, testing and site installation of all individual lines and manifolds were carried out. The cryogen delivery system for superconducting magnet was initially completed. The superconducting cyclotron magnet was energized and magnetic field mapping of the cyclotron magnet was carried out. Magnetic field mapping of the superconducting magnet was required for carrying out harmonic analysis of the magnet, applying corrections on it and making it suitable to be used as a cyclotron magnet. After completion of magnetic field mapping, the complete system was shut down and warmed up. Cryogenic transfer lines to the cyclotron magnet were disconnected and the superconducting coil cryostat was removed. Assembly of trim coils with the magnet and assembly of the radio frequency structure were taken up.

Design and fabrication of individual lines, basement mezzanine manifold and basement manifold were completed according to strict quality assurance plan. The quality assurance plan comprised identification of material source, mechanical tests for materials, welders qualification, radiography of welds on process pipe, MSLD of joints, combined pressurization and leak test, boil off test. Inspection and testing of all individual lines and valve boxes were successfully completed at the vendor's works. After receipt of the components at VECC, site installation of cryogen delivery system for the cryopanel was taken up. Individual piping sections and manifolds were installed and interconnected. These sections were then tested using a mass spectrometer leak detector. Baking and evacuation were, then, carried out for the site welds and the installation work was completed.

SYSTEM COMMISSIONING AND TEST RESULTS

All the process lines were evacuated and purged with respective process gases to reduce the moisture level before cooling down the system [5]. Liquid nitrogen flow through the system was initiated and sustained. The cyclotron magnet cryostat was cooled down along with the helium refrigerator to a

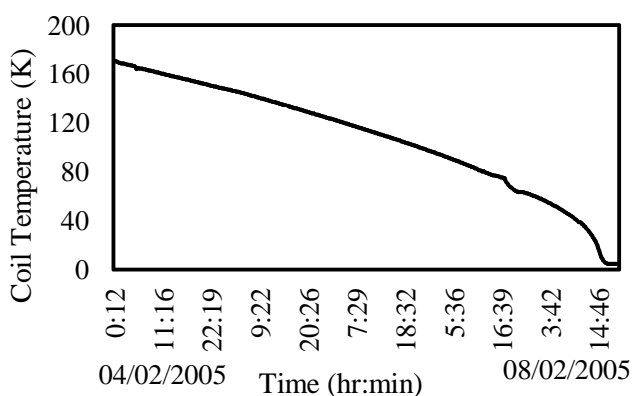


Figure 4 Cool down of cyclotron magnet

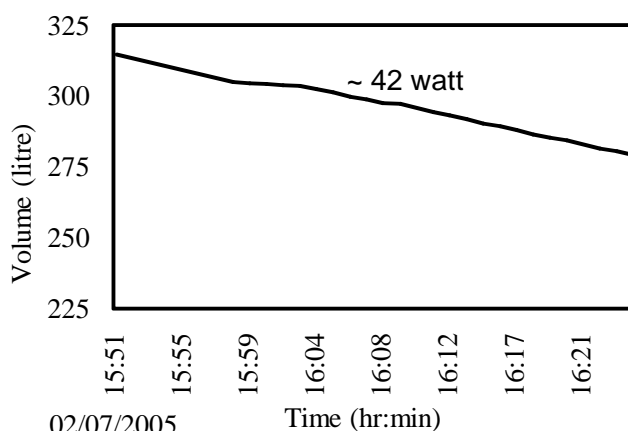


Figure 5 Load test for cyclotron magnet

temperature of about 10 K. Figure 4 gives the cool down curve for the cyclotron magnet. Thereafter, the magnet cryostat was cooled to 4.5 K by supplying liquid helium from the 1000 litre helium dewar. The cyclotron magnet was energised for about a year and magnetic field measurement of the cyclotron magnet was carried out. In order to assess the heat load of the cyclotron magnet, tests were carried out (Figure 5). It was observed that the heat load of cyclotron magnet cryostat was about 42 watt at 4.5 K at 80% level.

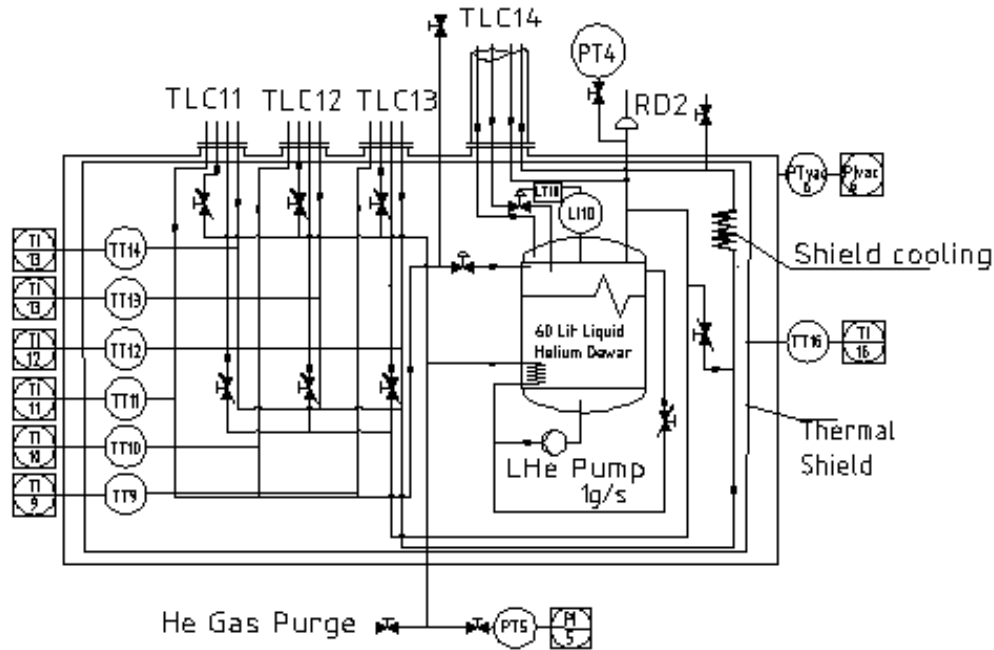


Figure 6 Flow scheme of cooling cryopanel with liquid helium (before modification)

After completing magnetic field measurements, the cryogen delivery system for cryopanel (Figure 6) was installed. The cold heads for liquid helium and liquid nitrogen were enclosed in vacuum enclosures and the enclosures were evacuated. Temperature sensor and heater were put on one of the helium and nitrogen cold heads. After cooling the liquid nitrogen system, the helium system was cooled, the helium pump sump was filled with liquid helium and the pump was operated. The desired cooling was not observed at the cold head of the cryopanel. A minimum temperature of 11 K was observed at the temperature sensor. Measurement of liquid helium flow was not incorporated because of the uncertainties and cost involved. The pump was operated at different speeds and different pressures varying pressure drop across the control valve. The heat load of the basement manifold was found to be ~ 5 watt (Figure 7). Theoretically, the system was perfect. It was presumed that liquid helium at the inlet of the pump might not be saturated because of the presence of after-cooler in the pump sump and length of pipeline at the inlet to the pump. An inducer at the inlet of pump would require lower NPSH.

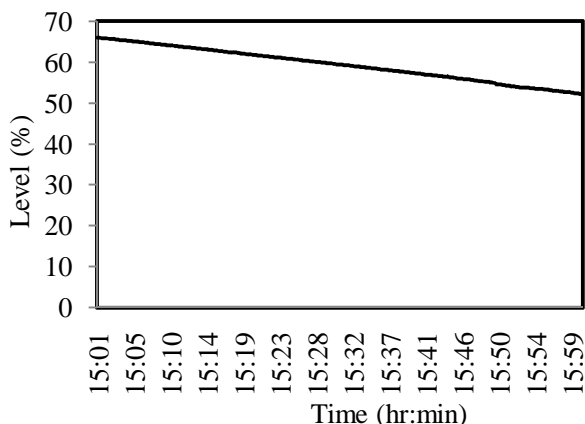


Figure 7 Heat load test for basement manifold



Figure 8 Liquid helium pump fitted with inducer

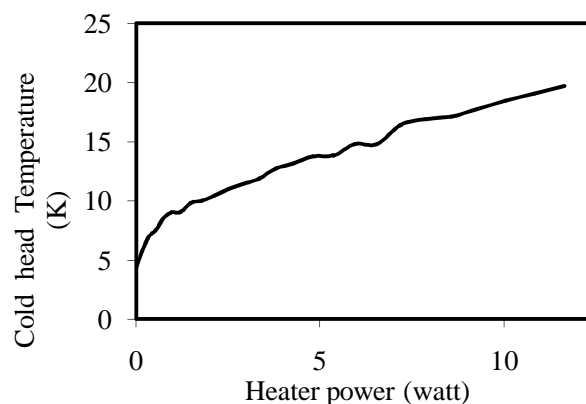
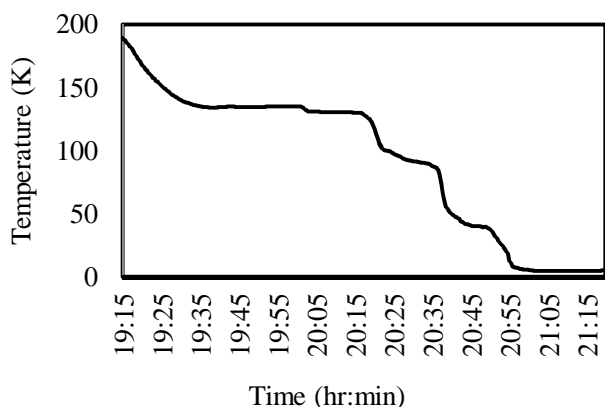


Figure 9 Cool down of helium cold head for cryopanel

Figure 10 Performance test of helium cold head for cryopanel

Addition of an inducer at the inlet of the pump (Figure 8) did not help to improve the performance of the system. Different options were examined for improving cooling at the cold head of the cryopanel. Addition of sub-cooler and phase separator were considered. However, addition of sub-cooler and phase separator involved additional time and resources. A modification in the helium circuit (Figure 1) was considered, where the high pressure helium liquid instead of returning to the pump sump after cooling the cryopanel returned to the liquefier. This alternative allowed the pressure head of the helium liquefier and that the pump to generate flow through the cryopanel. Modifications were carried out in the helium circuit based on this alternative. The after-cooler was removed, thermal shielding was provided to inlet line to the pump and helium gas bleed was incorporated to reduce heat leak to the pump. The system was cooled down after carrying out these modifications. The modifications carried out helped to cool the cold head for cryopanel to 4.5 K (Figure 9). The performance of the cold head was tested by energizing the heater placed on the cold head (Figure 10). Although, the actual heat load on a liquid helium cold head was around 6 watt, the heater mounted on the liquid helium cold head was energized corresponding to a heat load of 12 watt. The temperature of the cold head was observed to be below 20 K upto a heat load of 12 watt. The cryogen delivery system for cryopanel was successfully commissioned.

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