COMMISSIONING OF THE MAIN MAGNET OF KOLKATA K-500 SUPERCONDUCTING CYCLOTRON

Rakesh Kumar Bhandari, Bikash Sinha, Variable Energy Cyclotron Centre, Kolkata-700 064, India

Abstract

Commission of the Kolkata K-500 superconducting cyclotron magnet has been underway at the Variable Energy Cyclotron Centre. The cooldown and energisation experience is described in this paper.

INTRODUCTION

The cyclotron superconducting magnet is designed to produce a maximum of about 6Tmagnetic field at 800A current [1]. The 80 tonne main magnet iron structure and coil cryostat had been installed at the cyclotron vault in late 2004. All the cryogenic lines, plant, power supplies and control systems are successfully commissioned. The magnet was cooled down to liquid helium temperature and filled with liquid helium early this year. Very recently, the magnet has been energised to 550A current producing 4.8T magnetic field in the hill region. The activity to ramp up to the full design current is going on.

ASSEMBLY

The cyclotron magnet along with various systems has been fully assembled in the cyclotron vault (fig. 1 and 2). A brief description is given below:

Installation of Different Systems

The magnet iron frame (80 tonnes) has been installed on pier supporting system, levelled within 800µ accuracy. The annular cryostat, housing NbTi superconducting coil, has been assembled with the iron frame with a 0.6mm concentricity and 0.25mm vertical positioning accuracy. The coil is suspended inside the cryostat by nine glass epoxy support links, three pulling upward, three downward and the other three pulling radially outward. The tensile forces in the support links are monitored by strain-gauged-studs. A 50-litres/hour capacity (without pre-cooling) helium liquefier has already been installed alongside the cyclotron building. The vacuum jacketed and liquid-nitrogen-shielded transfer lines along with valves, manifolds and sensors have been installed connecting the helium cold box and nitrogen delivery system to the cryostat. The overall control system based on industrial PLC and HMI software has been successfully tested and commissioned. This control system takes care of all the cryostat and cryogen delivery system sensors, and uses these signals to control different valves and generate alarms. A turbo molecular pump backed by a scroll pump maintains 10^{-6} mbar pressure in the cryostat outer vacuum chamber. Two 1000A, 20V power supplies with 10-ppm stability for the main coil along with air-cooled dump resistors and control software have been installed and commissioned. The magnetic field measurement setup, which uses optical encoder, stepper and smart motor driver, has been commissioned. The magnetic field mapping will start soon.

Figure 1: Cyclotron magnet assembly with cryogenic systems.

Figure 2: Cryostat assembly during installation.

COMMISSIONING OF THE MAIN SUPERCONDUCTING MAGNET

The commissioning process started towards the end of 2004. The superconducting coil has been cooled down to 4.5K and energized up to 550A producing 4.8T magnetic field in the hill region.

 0-7803-8859-3/05/$20.00

Magnet Cooldown

The moisture level in the liquid helium chamber was first reduced below 20 ppm level (fig. 3) by repetitive evacuation and purging with pure helium gas and heating the coil with 5A current [2].

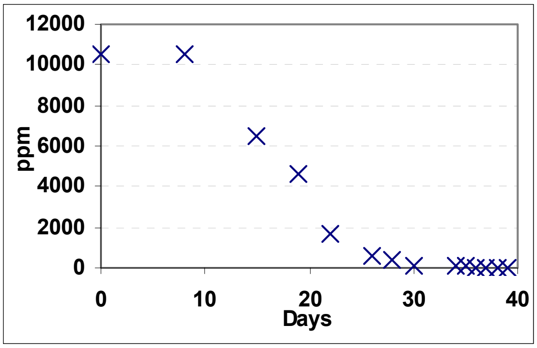

Figure 3: Moisture level in the liquid helium chamber.

Subsequently, the cool down process started by sending cold helium gas from the plant to the cryostat. Liquid nitrogen cooling to the radiation shield was unavailable this time due to a fault in the nitrogen plant. Still the helium liquefier was capable enough to cool the coil to 4.5K and fill it with liquid helium (fig. 4) [3]. Subsequently, the liquid nitrogen supply to the shield was restored. During this process, an increase in cryostat outer vacuum chamber pressure halted the cooldown activity. Leaks were suspected in the liquid nitrogen lines in the shield. After a couple of weeks of chasing, leaks were detected on the current lead bellows and were fixed. The coil was again cooled below 10K and the liquid helium was poured into the cryostat.

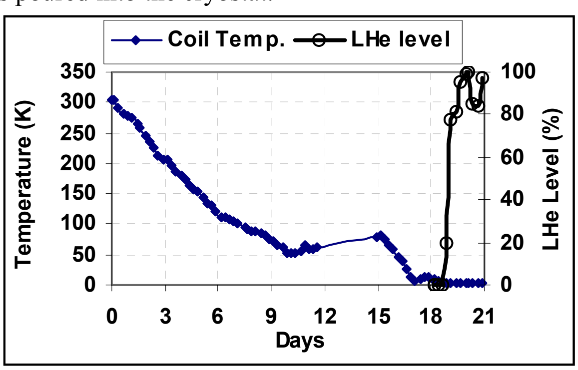

Figure 4: Coil temperature and LHe level without liquid nitrogen shield cooling.

During cooldown, the radial support link forces were adjusted to keep the forces within safe limit. At 154.4K temperature, the safety nut of the link #7 happened to share the entire load instead of the strain gauge stud due to human error. This is indicated as a sharp dip in figure 5. This problem was also fixed.

A boil-off measurement was carried out to find the cryostat heat load. The liquid helium was allowed to evaporate from the cryostat keeping the pressure constant. The heat load was found to be about 23W.

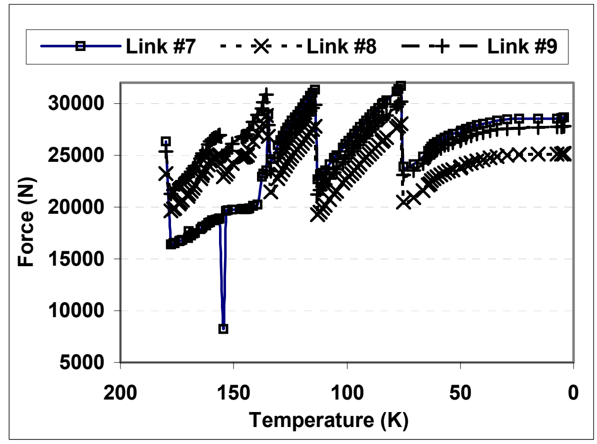

Figure 5: Radial link force adjustment during cooldown.

Magnet Excitation

After stabilizing the required liquid helium level in the cryostat for a couple of weeks the magnet excitation was initiated. All the safety interlock systems were tested by forcing the coil current decay through slow and fast dump resistors. Figure 6 shows fast dump current decay test results. A typical slow dump characteristic of the coil is shown in figure 7.

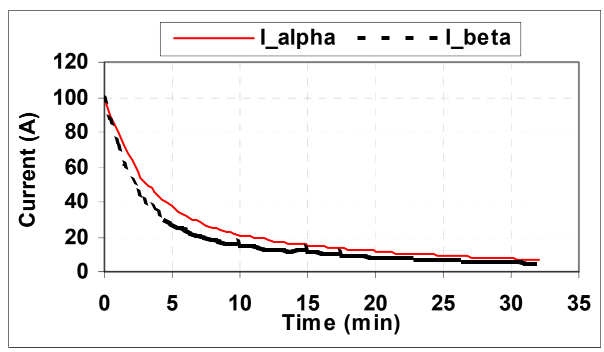

Figure 6: Fast dump test.

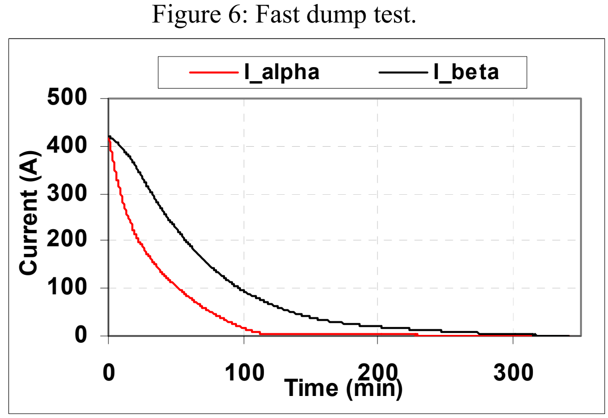

Figure 7: Slow dump at 400A.

Several iterations were required for coil centering procedure and plant parameter adjustment before reaching 550A current and 4.8T magnetic field at 33cm radius in the hill region (figure 8).

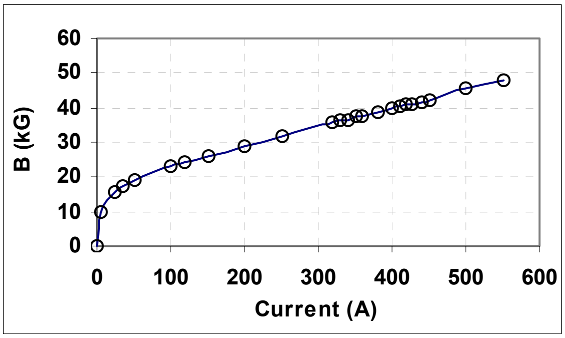

Figure 8: Magnetic field at 33cm radius in hill region.

Coil Centering

The coil experiences position and current dependent force, which was observed as change in the radial support link forces. The forces on the radial support links decrease with current due to expansion of the coil in response to the magnetic hoop stress. Because of the placement inaccuracy of the coil with respect to magnetic axis of symmetry, the resultant magnetic force on the coil tries to move it. Hence, the forces on the support links decrease towards the side the coil moves and increase on the other side. This magnetic force depends on the magnetic field and the field gradient where the coil is placed. Hence, the coil needs to be moved to a position where the coil axis matches with the magnetic axis of symmetry. The coil is given a series of shifts by rotating the nuts connected with the radial support links, so that the forces do not increase over the full range of operating current, as shown in figure 9. Finally, all three radial support link forces show a monotonic decrease with current, as shown in figure 10.

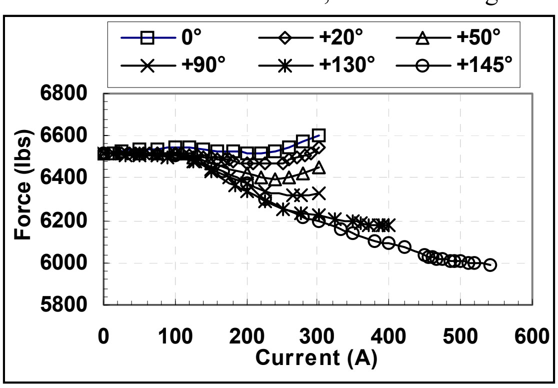

Figure 9: Force on link #9 at various adjustments.

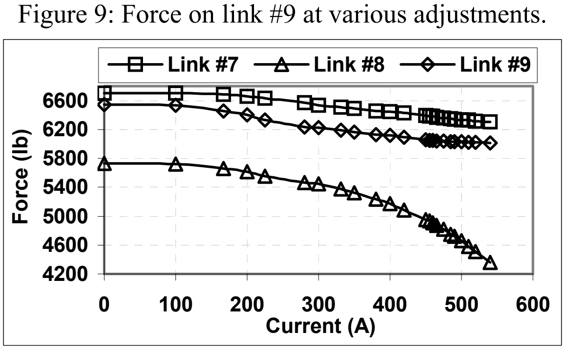

Figure 10: Radial support link forces vs. current.

The magnetic forces on the coil were measured as changes in the radial support link forces and their resultant magnitude and direction were calculated. During the centering process, this resultant force was minimised by giving a shift in the opposite direction of this resultant reaction force. After each iteration it was found that the force is getting minimised for higher range of current (figure 11). In figure 9 and 11, '+' rotation means tightening the link.

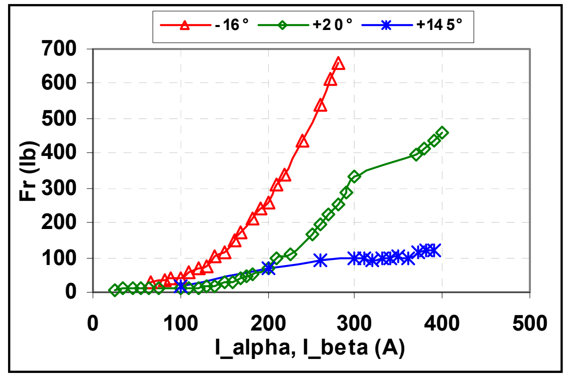

Figure 11: Resultant reaction force at different coil shifts.

CONCLUSIONS

The process of energizing the coil to full current, i.e. 800A, is continued. Subsequently, elaborate field measurement will be carried out. The cyclotron is expected to accelerate the beam with radio frequency system, ECR ion source, and injection and extraction line installed and commissioned by middle of 2007.

ACKNOWLEDGEMENT

This work is a combined effort of several dedicated scientists and engineers of the Centre. Their contributions are gratefully acknowledged. We are particularly thankful to our young colleagues Tamal Bhattacharyya, Malay Dey, Anjan Dutta Gupta and Tanmoy Das for their invaluable help in preparing this paper.

REFERENCES

[1] Rakesh K. Bhandari, "Status of the K-500 Superconducting Cyclotron", Proc. of Indian Particle Accelerator Conference (InPAC-2005), Kolkata, March 1-5, 2005, p. 1.

[2] G Pal, C Nandi, T K Bhattacharyya and others "Commissioning of Cryogen Delivery System for Superconducting Cyclotron Magnet", Proc. Of InPAC-2005, p. 481.

[3] R Dey et. al., "Operational Experience of Helium Liquefier-Refrigerator after Interfacing with K500 Superconducting Cyclotron at VECC, Kolkata, India", Proc. of InPAC-2005, p. 479.

0-7803-8859-3/05/$20.00