COMMISSIONING STATUS OF KOLKATA SUPERCONDUCTING CYCLOTRON

Chaturanan Mallik & Rakesh K. Bhandari (on behalf of VECC Staff)
Variable Energy Cyclotron Centre, Kolkata, India.

Abstract

After completing the construction of the K~500 superconducting cyclotron at Kolkata, the internal beam acceleration was accomplished in August 2009 and several tests were conducted to confirm the acceleration. Earlier the superconducting magnet using Nb-Ti superconductor with 300 litre liquid helium cryostat and 80 tonne iron was commissioned and field mapped. The radiofrequency system spanning 9-27 MHz and with three independent resonators were integrated into the machine. Some difficulties were experienced with achieving the voltage related to ceramic failures. Finally, ~50 kV on the dees have been achieved with reasonable phase stability between the three dees. The cyclotron uses a 14 GHz external ECR ion source and the beam is injected through 28 metre long injection line. Till date several beams like neon, argon, nitrogen, oxygen etc. have been accelerated. Valuable experience has been obtained with various systems. Presently, beam extraction is being tried and will be achieved shortly.

FIRST BEAM ACCELERATION

Kolkata Superconducting Cyclotron project was started at VECC during late nineties where already a K=130 cyclotron has been operating since 1978 and being used for basic research. The superconducting cyclotron magnet using Nb-Ti superconductor with 300 litre liquid helium cryostat and 80 tonne iron was commissioned and field mapped in 2006. The magnet has been running continuously ever since then. After completing the fabrication of major components like RF, injection system, beam chamber, isochronous coils, power supplies, diagnostics and extraction systems the superconducting cyclotron was assembled and integrated by early 2009. Every attempt was made to fabricate them indigenously and many critical components had to be fabricated in-house. During integration the major problems encountered were related to obtaining vacuum in beam chamber without the cryopanels. Considerable time was invested in conditioning the cyclotron with voltage on the dees. In the mean time the 28 metre injection beam line was also installed. The ion source which was coupled to the cyclotron was the 14 GHz ECR source which had served quite well with the K=130 cyclotron and large experience had already been gained in its operation. No provision for internal ion and from its beginning it was decided to have first acceleration with external source. The internal beam acceleration was accomplished in August 2009 and several tests were conducted to confirm the acceleration. After the acceleration extraction system was put in place along with enhancement in cryogenic plant capabilities.

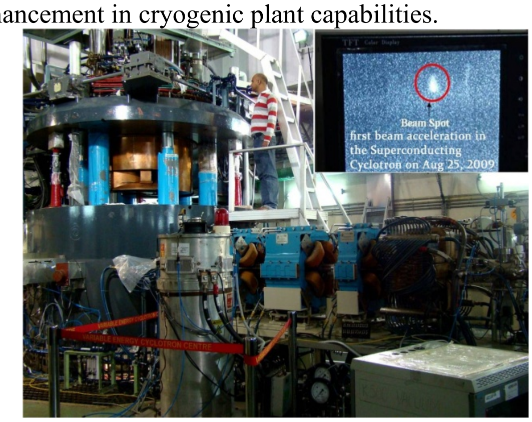

Figure 1: The superconducting cyclotron and external beam line in cyclotron vault. The inset shows the beam spot on ZnS screen in the acceleration chamber

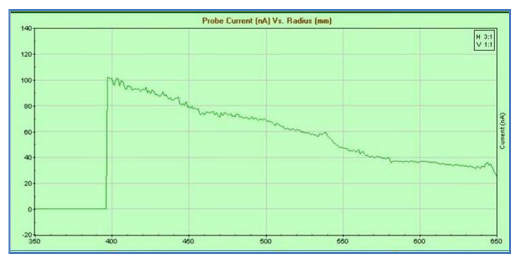

Figure 2: Beam current vs. radius during initial trials

Till date several beams like neon, argon, nitrogen, oxygen etc. have been accelerated to the extraction radius. Valuable experience has been obtained while operating various subsystems and improvements have been made. The vacuum in the beam chamber has been improved considerably using helium cryopanels. The stability of the RF system has been improved. Presently, beam extraction is being tried and hopefully will be achieved shortly.

IMPROVEMENT IN ACCELERATED BEAM CURRENT

Due to the unavoidable and inherent compact geometry of the cyclotron and the problem of stray magnetic field the turbo-scroll pumping modules are kept far apart in a position where stray magnetic field is not more than 25 gauss. These two constraints limit the conductance as well as effective pumping speed of turbo molecular pump to a great extent. Provisions of three numbers of cryopanels to be used to achieve more pumping speed and better vacuum were made but was planned to energise after enhancement of the cryogenic plant.

Initial beam acceleration was tried with turbo pumps but the beam profile showed loss of beam with radius as shown in Fig. 2. Then it was decided to energise the cryopanels with liquid nitrogen. That improved the vacuum but surprisingly there was no impact on the beam loss profile.

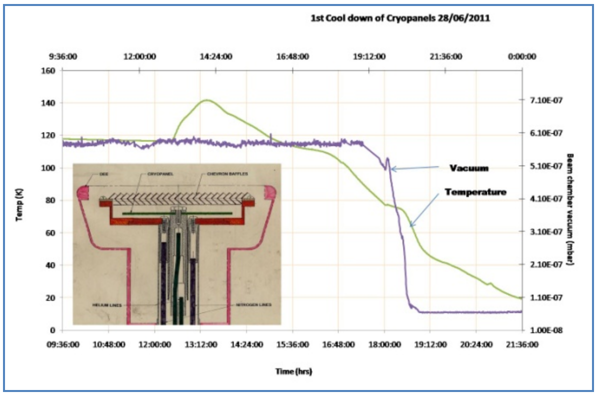

Figure 3: Temperature of cryopanels and beam chamber pressure.

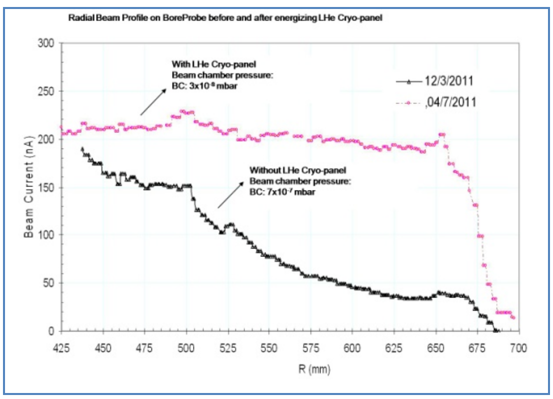

Figure 4: Frequency error along radius

After the enhancement in the cryogenic plant capability which was taken up after the first beam acceleration it was decided to incorporate the helium cryopanel even though the chamber had shown better vacuum by reducing the water partial pressure drastically with liquid nitrogen. The results of helium cryopanel are shown in Fig. 3. The results were extremely satisfying in terms of beam survival with radius as shown in Fig 4. Hence the availability of beam at extraction radius was pronounced for extraction trials.

To analyze and understand various vacuum related problems, residual gas analyzer (RGA) has been used. When RF conditioning was started, the partial pressure of hydrogen gas is significant as is evident. Hydrogen outgases from metallic surface at high RF power, hence need of additional pumping for hydrogen is being realised. It is planned to use activated charcoal at the bottom surface of 10K cryo-panels so that hydrogen could be pumped out effectively by cryo-adsorption.

ION SOURCE AND INJECTION SYSTEM

The ECR ion source operates at 14.4 GHz microwave frequency at maximum of 1KW of power to produce light ion beams such as N, O, Ne, Mg, Al, S etc. and heavier ion beams like Ar, Kr, Xe etc. The heavy ion beams, produced in ECRIS, are charge/mass separated by an analyzing magnet and then guided through two horizontal beam line sections and bend downwards (~28m length in total) to be injected into the cyclotron through its axial hole. The beam injection system consists of solenoid magnets, steering magnets, diagnostics elements, vacuum pumps and the spiral inflector. The horizontal part of the beam line, starting from ECRIS to the vertical bend is shown in figure 5.

Figure 5: The ECR ion source and injection beam line in the high bay.

The injection beam line is designed for the maximum beam rigidity of 0.058 T-m, which corresponds to ions with specific charge (η=q/A) equals to 0.12 and energy equals to (20*η) keV/nucleon, 20 kV being the maximum extraction voltage of ECRIS.

RF SYSTEM

The radio-frequency system of superconducting cyclotron consists of three λ/2 RF resonator cavities powered individually by 80 kW radio-frequency amplifiers via three hydraulically driven coupling capacitors through three rigid coaxial transmission lines with 50Ω characteristic impedance. The fine frequency tuning (±0.3%) of the cavity is achieved by a hydraulically driven Trimmer Capacitor. After several optimizations stability in dee voltage has been achieved. The inter dee phase stability has also been improved considerably to obtain a reasonable beam stability.

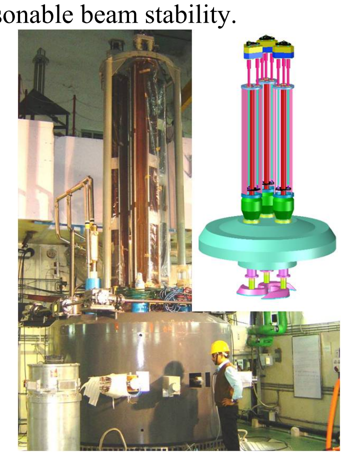

Figure 6: The upper half of the RF system (inset shows the 3D model)

During last year the dee stem ceramic insulators cracked several times. Each failure caused several weeks of shutdown, since changing the ceramic insulator requires dismantling of the whole RF cavity. An exhaustive thermal analysis has been carried out. The problem still needs to be resolved and studies are being made.

For extraction, balancing of dee voltage is important and presently we are making use of X-ray end point measurement to establish the near accurate value of the dee voltage.

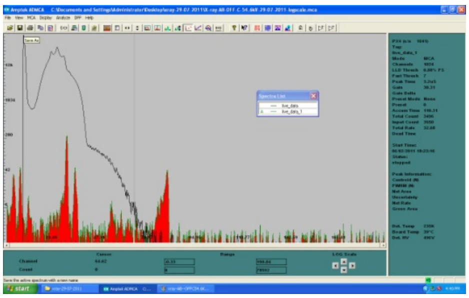

Figure 7: Bremsstruhlung X-ray measurement to determine the Dee voltage.

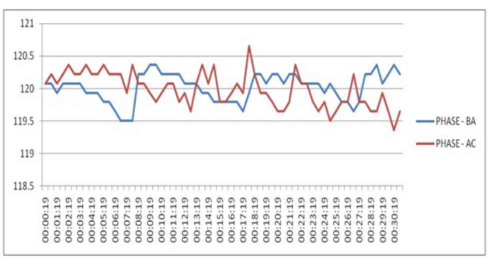

Figure 8: Improvement in inter-Dee phase stability (within +/-0.5degree).

DIAGNOSTICS

The injection line has several diagnostics like segmented Faraday cups and slits along the 28 metre line. The acceleration chamber has three finger probe for vertical beam studies and differential probe for centering and it runs along the middle of the hill on the liner track. We have also incorporated ZnS screen as borescope probe to visually see the beam at outer radius and it moves straight radially until 400 mm radius. However we have provisions to convert it to current measuring probe which we have used for rough centring by shadowing technique. In the extraction side we have eight passive magnetic channels which have current measurement facility to aid in the complex extraction procedure.

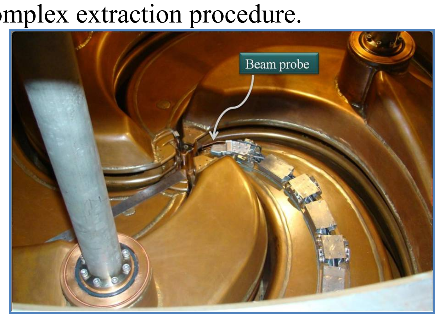

Figure 9: Three finger probe with 100 micron differential probe mounted on the head.

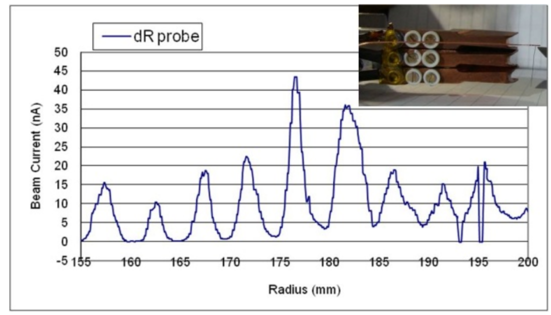

Figure 10: Beam profile measured by differential probe showing well separated turns in the initial acceleration zone.

EXTRACTION SYSTEM

Two deflectors and nine magnetic channels including an active magnetic channel have already been installed A deflector test stand had already been setup. The deflector system has been tested there satisfactorily with more than 60 kV over 6 mm gap and less than 100 nA dark current.

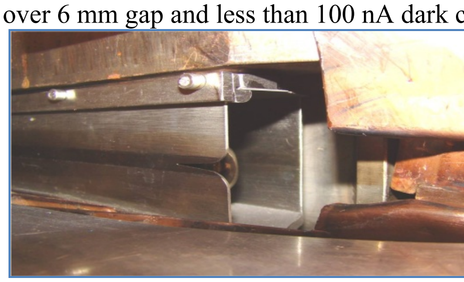

Figure 11: The first electrostatic deflector with 8mm gap between the electrode and septum.

Presently beam extraction is being tried after achieving sufficient current at the extraction radius.

REFERENCES

[1] C. Mallik, et. al., "First Beam Acceleration in Kolkata Superconducting Cyclotron and its Present Status, 19th International Cyclotron Conference, 2010, Lanzhou, China.

[2] 'Status of K500 Superconducting cyclotron project at Kolkata' Rakesh Kumar Bhandari and Bikash Sinha (for VECC Staff), International Conference on Cyclotrons and Their Applications 2007, Italy.

[3] 'Magnetic Field Mapping of Kolkata Superconducting Cyclotron': C. Mallik, et al., Proc.of the 18th Int. Conf. on Cyclotrons and Their Applications 2007, Oct. 1-5, 2007, Giardini Naxos, Italy, page 435.

[4] 'Fabrication and Installation of Radio Frequency Cavity for K500 Superconducting Cyclotron at Kolkata' paper presented at IPAC-2010(23-28 May, 2010) M. Ahammed et. al.

[5] 'Development of RF system for Superconducting cyclotron at VECC, Kolkata': S Som, et. al. Proc. of Intl. Conference on cyclotrons and their applications-2007, LNS, INFN, Catania, Italy.

[5] 'Fabrication of Extraction System for Superconducting Cyclotron", S Bhattacharyya et. al., Proc. of Indian Particle Accelerator Conference, March, 2005, VECC, Kolkata.