FIRST BEAM ACCELERATION IN KOLKATA SUPERCONDUCTING CYCLOTRON AND ITS PRESENT STATUS

Chaturanan Mallik and Rakesh Kumar Bhandari (on behalf of VECC Staff)
Variable Energy Cyclotron Centre, 1/AF, Bidhan Nagar, Kolkata - 700064, India

Abstract

Major subsystems of the superconducting cyclotron at VECC, Kolkata were integrated by May 2009. After achieving the required vacuum and Dee voltage a series of internal beam trials were started. The beam was accelerated to full extraction radius on August 25th and beam confirmed by neutron measurements.

The trials were not without difficulty and several problems did crop up during the initial phase. With minor modifications vacuum of the order of 10^{-7} mbar was obtained. Major problems encountered were related to obtaining sufficient Dee voltages primarily due to ceramic insulator cracking at moderate power levels leading to vacuum breakdown. Earlier the 14 GHz ECR ion source was connected with 23 metre injection line without much difficulty.

An analogue beam was also accelerated before taking a shutdown for installation of extraction system and major augmentation of cryogenic plant. Presently extraction of the beam is being tried. It is planned to transport the beam to already installed first experimental station.

INTRODUCTION

The superconducting cyclotron magnet was functional and the magnetic field mapping and corrections were implemented by mid 2006. These developments were reported in the last cyclotron conference. Later the coil was warmed up to assemble other systems of the machine, like RF resonators, cryo-panels, 14 GHz ECR Ion source, 23 metre injection line, extraction system and augmenting main vacuum system. A significant part of the effort related to develop supervisory control and monitoring system for each subsystem incorporating present day tools.

Obtaining vacuum ~10^{-6} mbar in the beam chamber pumped by turbopumps without magnetic field and RF could be obtained relatively easily. Subsequently with magnet energised few leaks were detected and rectified. After having obtained ~10^{-6} RF conditioning was started. Several major problems cropped up in terms of 'viton o-ring' degradation and ceramic cracking at very moderate RF power levels (15 kW). Considerable time was invested in understanding the problem (being detailed later). The problem was circumvented but only partially. However a dee voltage of 45 kV was available and it was decided to try the first internal beam.

FIRST INTERNAL BEAM

It was very tempting to try the first beam as a test beam after 45 kV Dee voltage at 14 MHz was obtained and the phase was stable to provide reasonable condition for acceleration.

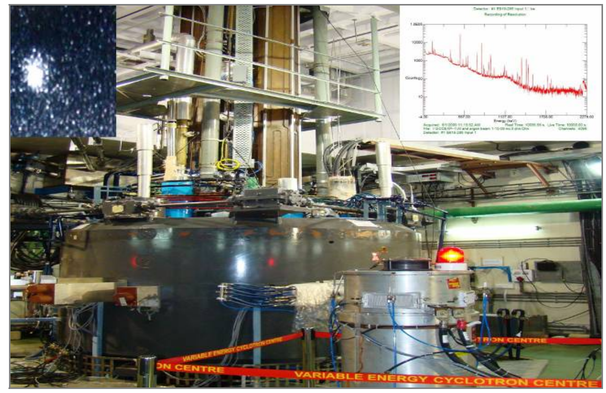

Figure 1: Superconducting cyclotron with first beam spot on left hand corner and gamma spectroscopy of the irradiated target in the right top corner

Initial plan after attempts for higher energy were shelved till suitable Dee voltages are available. And it was decided to accelerate Ne3+ in second harmonic mode at 30 kG at 14 MHz. The 14 GHz ECR Ion source was already relocated from k130 cyclotron to the superconducting cyclotron. All the diagnostics were already made functional after initial problems of measuring low currents in RF environment. In mid-august the above configuration was started as a beam test run. To our surprise it didn't take much time to obtain accelerating beam and the parameters were quite close to the calculated values. The beam was accelerated to full extraction radius on 25th August 2009. To confirm the beam an internal beam experiment with aluminium block attached to main probe was performed and all conclusive signature of beam was obtained.

Initial Observations

It was very satisfying to see that the parameters for magnetic field actually obtained during the test beam run were close to the calculated values. The dee voltages were estimated from pickup probes as the cadmium telluride based detectors are still being implemented to get fairly accurate values.

ECR Ion Source and Injection System

14.4 GHz Electron Cyclotron Resonance Ion Source was relocated from room temperature cyclotron and integrated to the superconducting cyclotron by a 28 metre injection system and a spiral inflector. 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.

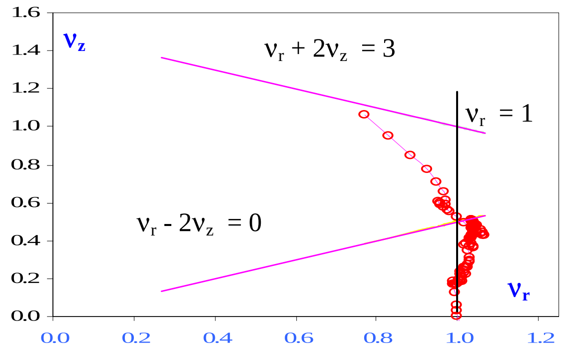

Figure 2: Tune diagram for the Test beam (Ne^{3+}, 4.5 MeV/u, B_0=30.5 kG)

Figure 3: Current vs. radius for the Ne3+ beam

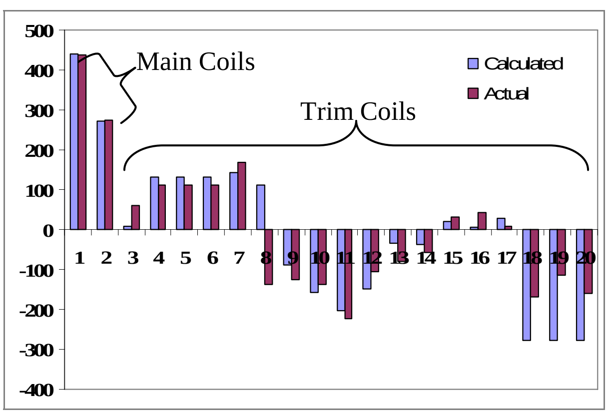

Figure 4a: Calculated and experimental value of main coil and trim coil current settings (in Amp) for Ne3+ beam at 4.5 MeV/u, B0=30.5 kG,, h=2, RF=14 MHz.

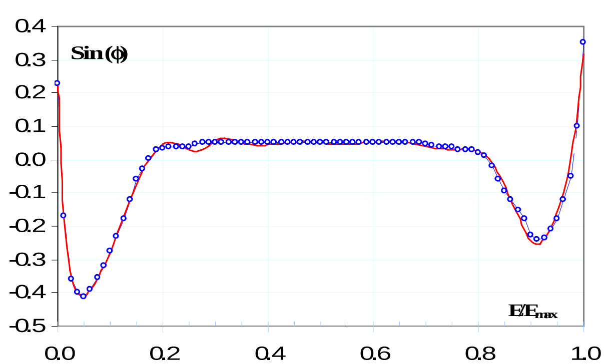

Figure 4b: Energy vs. Phase history for the Ne^{3+} beam

Operation of cyclotron with low magnetic field limited the ion beam injection voltage and due to this limitation ECR ion source was operated with low extraction voltages. With persistent operation of ECR ion source the extraction electrode was eroded due to diverging ion beam causing sputtering of electrode. This problem was overcome by changing the gap of extraction electrode from 35 mm to 25 mm. Now the ECR ion source operated with better stability as well as produces more currents. For last one year, the same electrode is under use and there is no deterioration in the performance.

Figure 5: Installed ECR Ion Source and Injection Line

Figure 6: Vertical injection line on top of yoke

SOME SYSTEM MODIFICATIONS AND IMPROVEMENTS

Radiofrequency System

The radio-frequency system of superconducting cyclotron consists of three λ/2 RF resonator cavities powered individually by 80 kW radio-frequency amplifiers (Figure-1) via three hydraulically driven Coupling Capacitor through three rigid coaxial transmission line with 50Ω characteristic impedance. The fine frequency tuning (±0.3%) of the cavity is achieved by a hydraulically driven Trimmer Capacitor. The actuators and servo valves are driven from a common power pack with computerized control system to give the Trimmer Capacitor paddle

Trimmer capacitor hydraulic drive control system was developed for fine frequency tuning of the RF resonating cavities. While conditioning the RF system, wild hunting of the hydraulic actuator was observed causing fluctuations in the Dee voltages. The problem is partially solved by tuning the hydraulic system. It has been done by adjusting the pressure and flow of oil through the servo valves. Provision for online control of gain was introduced to make the system suit to our requirement. A PC-PLC-based hydraulic drive system with precise movement (< 50 μm) has been developed indigenously for fine tuning the cavity using Trimmer capacitors and also for feeding RF power to the cavity by impedance matching through coupling capacitors.

During last year the ceramic insulators cracked several times due to excessive dielectric-heating. Each failure caused several weeks of shutdown, since changing the ceramic insulator requires dismantling of the whole RF cavity. An exhaustive thermal analysis was carried out to estimate the required air-flow rate for cooling the ceramic and analysis results were verified by simulating an off-line experimental set up. Finally the cooling was provided to the ceramics by turbine blower and improvement was observed.

During RF conditioning of the resonator cavity, there is heating in the O-ring made of viton placed with the ceramics and consequently degradation of vacuum. It is found from operational experience that silicone O-rings provides better performance in this atmosphere over viton O-ring. Therefore, all the viton O-ring, which are in a highly inaccessible zone, has been replaced by silicone O-rings.

Figure7a. Cyclotron with Zero degree Extraction Beam line, (7b) Coupling capacitor

Vacuum System

Due to the unavoidable and inherent compact geometry of the cyclotron, pumping port of beam chamber is only of 3 inch diameter. Again 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. For example, though the pumping speed at the inlet port of module is ~ 500 Lt/s, net pumping speed reduces to ~ 50 Lt/s at the Beam chamber. Three numbers of cryo-panels made of OFHC copper have been used to achieve more pumping speed and better vacuum.

Detoriation of OVC (Outer vacuum chamber) vacuum is more pronounced with increasing current in small (alpha) coil. As there is no provision to find out the cold leak, extra pumping port of net conductance 150 Lt/s has been introduced in the OVC. **This has improved the OVC vacuum considerably.**

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.

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, over several weeks.

CONCLUSION

The superconducting cyclotron at Kolkata has already accelerated the first beam. A long shut down had to be taken to augment the cryogenic plant and the extraction system along with external beam line connecting experimental station#1. Presently extraction is being tried out.

REFERENCES

[1] '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.

[2] '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.

[3] '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.

[4] '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.