SUPERCONDUCTING CYCLOTRON AND 224CM CYCLOTRON AT VECC KOLKATA: THEIR STATUS AND RECENT DEVELOPMENTS

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Abstract

The superconducting cyclotron project at VECC, Kolkata went through exciting developments after the last InPac conference when the first beam was accelerated in August, 2009. Major subsystems of the superconducting cyclotron briefly reported earlier were integrated by May 2009. After achieving the required vacuum and dee voltage a series of internal beam trials were started. The neon beam was accelerated to full extraction radius. Several internal experiments were carried out and beam confirmed by neutron measurements.

The trials were not without difficulty and several problems did crop up during the initial phase particularly after rf system was integrated and the dees were powered. Earlier the 14 GHz ECR ion source and 28 metre injection line were connected 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 out. It is planned to transport the beam to already installed first experimental station.

The VECC campus houses 224cm cyclotron which was commissioned way back in 1977 and has been delivering beams for the national users. As reported in earlier InPAC the cyclotron was shut down for a major upgradation and modernization of technical systems in 2007. Following the massive modernization effort the cyclotron has been re-commissioned in January 2010. Presently the cyclotron is delivering alpha beam with energy ranging from 30 MeV to 60 MeV and proton beam with energy ranging from 7.5 MeV to 15 MeV. This paper describes status and recent developments related to both the cyclotrons at VECC, Kolkata.

SUPERCONDUCTING CYCLOTRON

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 conference. Estimates of energy per nucleon achievable are shown in fig 3. Later the superconducting coil was warmed up to assemble other systems of the machine, like RF resonators, cryo-panels, 14 GHz ECR Ion source, 28 metre injection line 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.

Without exciting magnetic field and RF voltage vacuum of the order of 10^{-7} mbar in the accelerating chamber pumped by turbo pumps could be obtained. Subsequently with magnet energised few leaks triggered by high magnetic field were detected and rectified. After having obtained a vacuum of $\sim10^{-6}$ the process of RF conditioning was started. Several problems cropped up in terms of vacuum degradation and ceramic metallization and cracking at very moderate RF power levels (15 kW). Considerable time was invested in understanding the problem. However a dee voltage of 50 kV was available and it was decided to try the first internal beam.

First Internal Beam

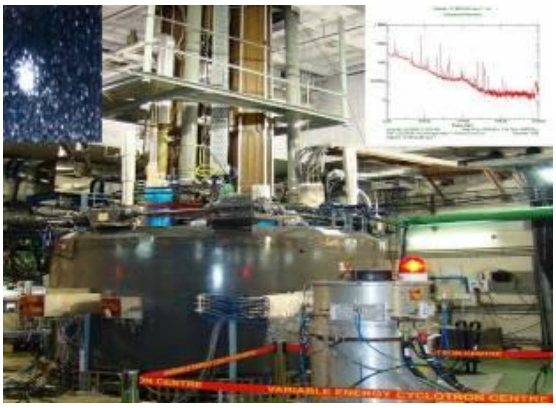


Fig. 1. Superconducting cyclotron with first beam spot on left hand corner and gamma spectroscopy of the irradiated target in the right top corner

It was decided to accelerate Ne3+ in second harmonic mode at 31 kGauss at 14.1 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 (Fig.1).

Accelerated Ne3+ beam was observed on Bore-scope beam viewer at 384 mm from centre for the first time on 14th August 2009. On 25th August 2009, the beam current up to 30 enA at 650 mm from centre was read by the main probe. Area neutron monitor placed near the exit port measured a neutron flux of 10 n/cm2/sec. A (5”x 7”) BC-501A liquid scintillation was placed along with standard Pulse Shape Discrimination Circuit (PSD) to detect both neutron and Gamma based on rise time dependent signals. The detector was place about 2 m away from the edge of the machine. The spectra show a clear evidence of neutron and gamma during operation of machine. The probe detected the beam all the way up till extraction radius as shown in fig. 2.

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.

Fig.2. Current vrs. radius for the Neon(3+) beam in nanoamperes

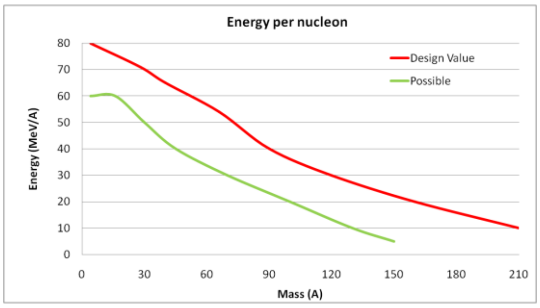


Fig.3. The graph shows energy per nucleon for different mass number which is expected to be available in first phase and the design values

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 28 metre injection system and a spiral inflector (Fig. 4).

Fig. 4 Installed ECR Ion Source and Injection Line

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

Radiofrequency System:

The radio-frequency system of superconducting cyclotron consists of three $\lambda/2$ RF resonator cavities powered individually by 80 kW radio-frequency amplifiers 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.

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.

Fig.5. RF structure with ceramic

During RF tests the ceramic insulators cracked several times due to presumably 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. This has resulted in stopping damage to o-rings but the ceramics still crack after prolonged use (fig 5).

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 cryopanels made of OFHC copper have been used to achieve more pumping speed and better vacuum.

To analyze and understand various vacuum related problems, residual gas analyzer (RGA) has been used. It is planned to use activated charcoal at the bottom surface of 10 K cryopanels so that hydrogen could be pumped out effectively by cryo-adsorption.

Beam Diagnostics:

Several beam diagnostics equipments have been installed inside the acceleration chamber. The train like probe (fig. 6) measures integrated current and differential probe in the form of 100 micron wire gives valuable information about the centring of the beam. This probe can also be used to sample vertical distribution of beam for diagnosing problems. In addition to this we have borescope probe which allows the beam to fall on zinc sulphide plate and view the internal beam. This probe will be useful to understand resonance related phenomenon as well as extracted beam. There are many diagnostics along the extraction path and the injection system.

Fig. 6. The train like movement of the main probe on the hill section which measures current versus radius. The picture also shows the dees and the centre region at top right corner

Extraction System and External Beam Lines:

Two deflectors and nine magnetic channels including an n 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 enA dark current, over several weeks.

The external beam line leading to Channel#1 is already in place (fig.7) and vacuum of the order of ~10^{-7} is already achieved in the beam line.

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

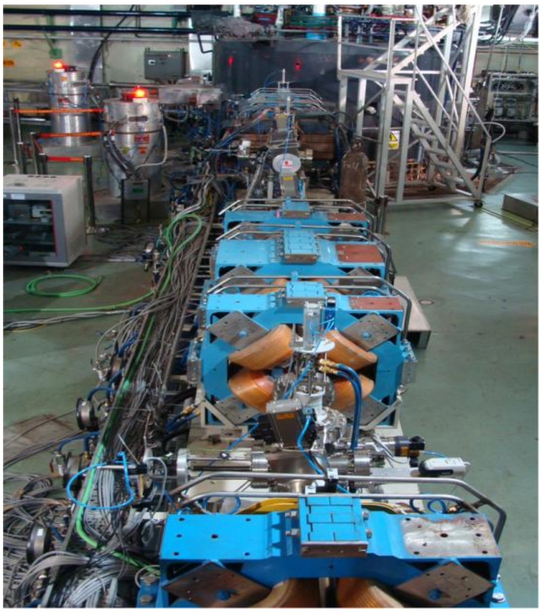


Figure 7. The external beam line leading to experimental station #1 in cave I

224 CM CYCLOTRON

The 224cm cyclotron at Kolkata popularly known as “room temperature cyclotron (RTC)” or the “VEC cyclotron” was the first big accelerator indigenously developed at VECC and commissioned in 1977. Initially it delivered light ion beams (proton, deuteron and alpha) to the users using an internal hot cathode PIG type ion source. From 1998, it also started delivering a variety of heavy ion beams using an indigenously developed 6.4 GHz ECR ion source. Later, another 14 GHz source was coupled to it and beam was injected into the cyclotron using a 20 metre injection line.

This cyclotron after having accelerated light ion beams from 1997 to 2007 was shut down for implementing large scale changes under the “Modernisation of VEC Technical Systems” project. The execution required access to active areas and the cyclotron itself so that modifications could be done.

During shutdown the major changes related to modifying subsystems which were either failing frequently or because their maintenance was posing difficulties as spares were not available. The major goal remained to make suitable modifications for converting this cyclotron as primary source of beams for producing exotic nuclei for Radioactive Ion Beam facility. Some of the works related to relocating the existing systems or even building new facilities.

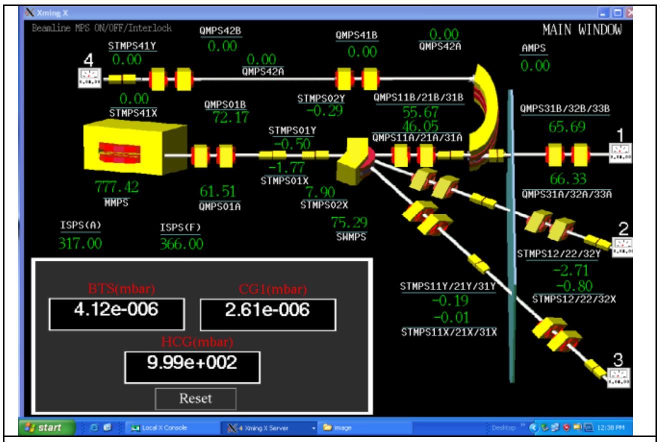
Some of the important works were

1. Changing the central region of the cyclotron to make it compatible with internal ion source
2. Changing "trim coil" power supplies(used for isochronizing the magnet field)
3. Changing the power supplies for the Radiofrequency system
4. Changing the main vacuum system and incorporating PLC based control
5. Changing the Freon unit for the vacuum system
6. Major modifications in Low Conductivity Water system and the Electrical system had to be carried out to incorporate above changes
7. Disconnecting the 6.4 GHz ECR ion source and the 14 GHz ECR Ion source from the cyclotron
8. The 6.4 GHz ECR ion source was substantially modified to make it a Low energy heavy ion facility for atomic physics and condensed matter physics
9. The 14 GHz ECR ion source was shifted to superconducting cyclotron.
10. Building new vacuum chamber for the 160 degree analyzing magnet which is expected to run in achromatic mode for the Radioactive Ion Beam Facility
11. The control console went for a major revision incorporating computerized control system for most of the subsystems
12. Radiation monitoring of active areas were revamped

Fig.8. the cyclotron and the first picture of extracted beam in the inset

The volume of work was really large and some unforeseen problems did crop up during implementation. Finally all the systems were energized in December 2009. First internal beam with the new setup was obtained in December 2009. On January 10, 2010 (Fig.8) external beam was obtained to everyone's delight. Since then the cyclotron continues to deliver proton and alpha beams on the targets. Presently the RTC is delivering alpha beam with energy ranging from 30 MeV to 60 MeV and maximum extracted beam current of about 12 µA. Proton beam with energy ranging from 7.5 MeV to 15 MeV is also being delivered with maximum extracted beam current of about 20 µA for 10 MeV protons. The stability and the quality of the beam have improved tremendously after the modernization of the RTC. The machine has already delivered beam for 3000 hours for conducting experiments in nuclear physics, radio-chemistry and material science as well as for pilot experiments for the production of radioactive be

In very near future this cyclotron will be used as primary source of light ion beams for the Radioactive Ion Beam Facility and produce exotic beam (Fig.9).



BTS(mbar) 4.12e-006

CG1(mbar) 2.61e-006

HCG(mbar) 9.99e+002

Figure 9. MMI interface showing the three beam lines and 160 degree bent line leading to RIB target at the end

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