BEAM TUNING IN KOLKATA SUPERCONDUCTING CYCLOTRON

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Abstract

The Superconducting cyclotron at VECC, Kolkata, has accelerated ion beams up to extraction radius successfully confirmed by the neutrons produced by the nuclear reactions. The internal beam tuning process started with beam parameters calculated using the measured magnetic field data [1]. Due to some mechanical and electrical problems we were forced to tune the beam with three major trim coils off. Accurate positioning of central region Dee-extensions ensuring the proper acceleration gaps in the first turn was required for successful acceleration of beam through the compact central region clearing the posts in the median plane. Here we present different aspects and results of initial beam tuning.

INTRODUCTION

The superconducting cyclotron at VECC, Kolkata, attained its major milestone in August 2009 when Ne^{+3} beam was accelerated to full extraction radius, after all the major subsystems were tested and operated synchronously. Beam acceleration involves following issues:

- Production of ion beam in the ECR ion source and transport the ion beam through 28 m beam line
- Transmission of beam through vertical beam line (~3 m) and axial cylindrical hole in the magnet yoke (~1.1 m) where high fringing field exists
- deflection of beam in the cyclotron median plane with a spiral inflector and clearing the central region by proper centering of the beam
- Obtaining isochronous magnetic field till extraction radius and accurate knowledge of beam dynamics in the cyclotron, which in turn required a very precise mapping of the guiding magnetic field inside the magnet and calculation of accelerating electric field.

Here we discuss the beam dynamical calculations using measured magnetic field data which helped in obtaining optimum settings for beam acceleration.

BEAM INJECTION

The ECR ion source operates at 14.4 GHz microwave frequency at maximum of 1 kW 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. Till now Argon and Neon ion beams have been successfully injected and accelerated. The heavy ion beams, produced in ECRIS, are charge/mass separated by an analyzing magnet and then guided through horizontal beam line sections and bend downwards (~22 m length in total) to be injected into the cyclotron through its axial hole[2]. The beam injection system consists of solenoid magnets, steering magnets, diagnostics elements, vacuum pumps and the spiral inflector.

Figure 1: The ECR ion source and injection beam line in the high bay (top) and the superconducting cyclotron along with external beam line in cyclotron vault (bottom).

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/u.

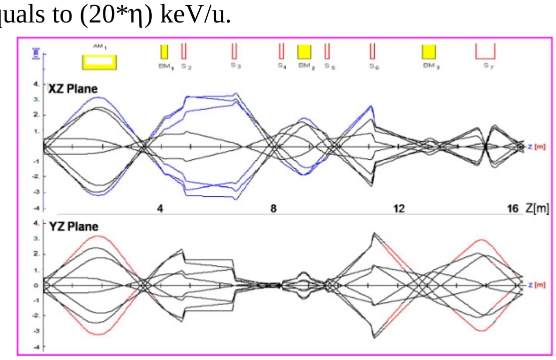

Figure 2: Beam profile along the injection beam line from ECRIS up to the matching point on the vertical beam line.

Along the axial hole large fringing field exists up to several meters from median plane (~10mT at 4m) which couples transverse motions of the charged particles resulting blow up or the beam. A long solenoid

(L_{eff}=63.5cm, B_0=1.57kG), placed just above the cyclotron yoke, is used for beam confinement and matching with the spiral inflector. The injected beam is bent into the median plane of cyclotron by a spiral inflector having aperture of 4 mm.

EQUILIBRIUM ORBIT PROPERTIES

The optimum isochronous field is produced by a pair of superconducting coils (main coils), the iron core and 14 trim coils. A field fitting code (TCFIT) is used to calculate the main coil and trim coil current settings required to produce an appropriate field for accelerating a beam to its desired final energy, with the constraint that the trim coils power consumption is minimum. The specific charge (Q/A), final energy and the energy vs. phase curve is given as input values. It also calculates the correct the RF frequency so that the energy spread is minimized at extraction radius. This is achieved by making $\int_{E0}^{E\max} \sin\varphi \, dE = 0$, where, $\sin\varphi(E) = \sin\varphi_0 + \frac{2\pi h}{qV_{dee}} \int_{E0}^{E} W(E)dE$.

This is the well known phase-energy relation for an accelerated particle in the cyclotron. The simulation results from '*TCFIT*' for the ion species: $^{20}Ne^{3+}$, E = 4.4 MeV/u, Bo=30.9 kG, ν_{rf} =14 MHz, h=2, are shown in following figure.

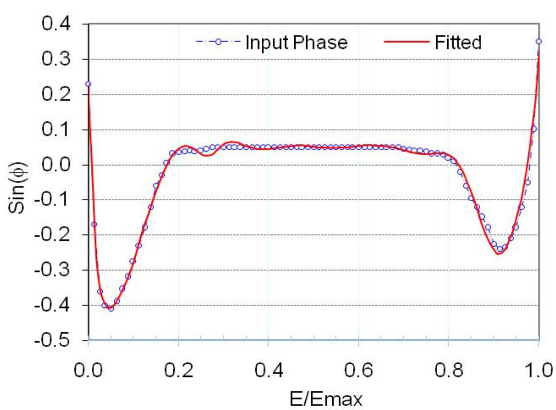

Figure 3: Input phase curve and fitted phase.

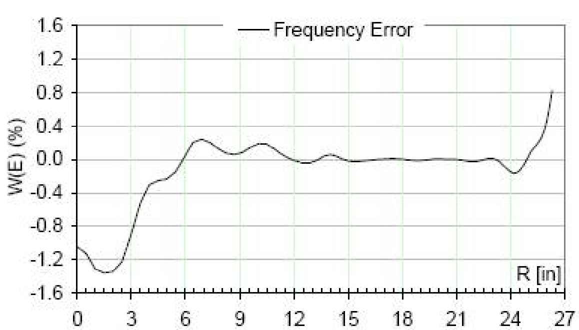

Figure 4: Frequency error along radius

The phase φ implies the particle timing relative to the RF accelerating voltage. The frequency error $W(E) = \frac{\omega}{\omega_0} - 1$, where $\omega_0 = 2\pi h \nu_{rf}$ and ω is the instantaneous particle angular frequency. This phase curve has been chosen to meet several important criteria. First the large initial positive phase is chosen to gain electric focusing (ν_z^2 =h Sinφ/2πn, n is the turn number) in the first few turns. The negative excursion and subsequent rise back to zero is a result of tailoring the magnetic field so that ν_z does not become too small (<0.1).

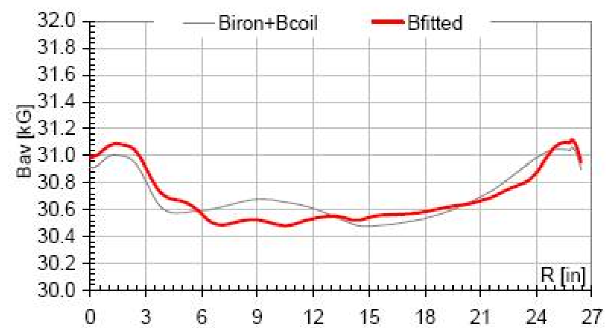

Figure 5: Field profile along radius at fitted current set

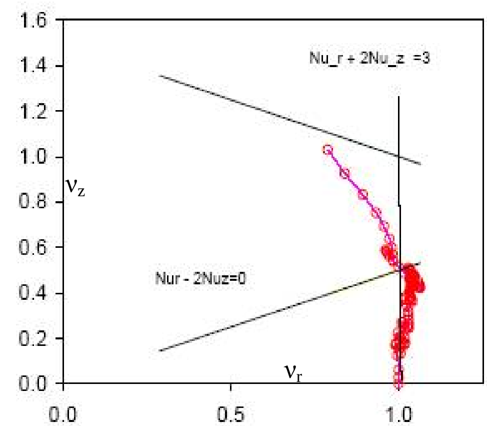

Figure 6: ν_r Vs ν_z plot

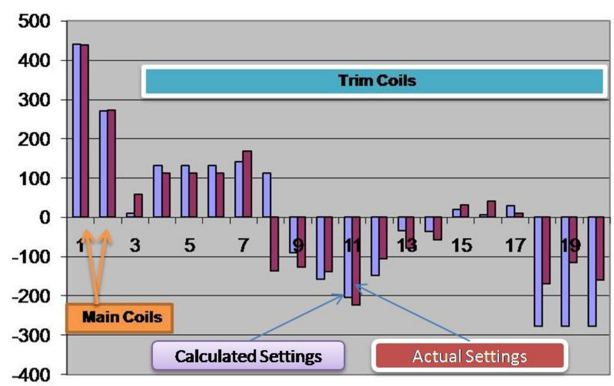

Figure 7: Comparison of the main coil & trim coil current settings

The frequency error W(E) corresponding to the optimized isochronous field is such that and the integral of sin(φ) near extraction is nearly zero ensuring minimum energy spread in the beam. The frequency error curve also shows that W(E) is nearly equal to zero from 6 to 24 inch radius suggesting good degree of isochronisms (fig 4). The initial large frequency error in the curve is due to the 'cone field' necessary for providing axial stability to the beam in the region where flutter is not sufficient.

As shown, the magnetic field can provide satisfactory horizontal and vertical focusing all along the accelerating path (fig 6). Another important beam dynamical issue that needs careful study is to ensure that the beam does not meet any devastating resonance $\nu_r+2\nu_z=3$ before being extracted and it crosses the $\nu_r=2\nu_z$ zone quickly. The tune diagram (fig 6) shows that the investigating species meets these two criterions satisfactorily.

SIGNATURE OF ACCELERATED BEAM

Accelerated Ne^{3+} beam in the VECC superconducting cyclotron was observed on bore-scope beam viewer at 384 mm from centre for the first time on 14th August 2009. The beam was accelerated in 2nd harmonic mode. On 25th August 2009, the beam current up to 30 nA at 650 mm from centre was read by the main probe.

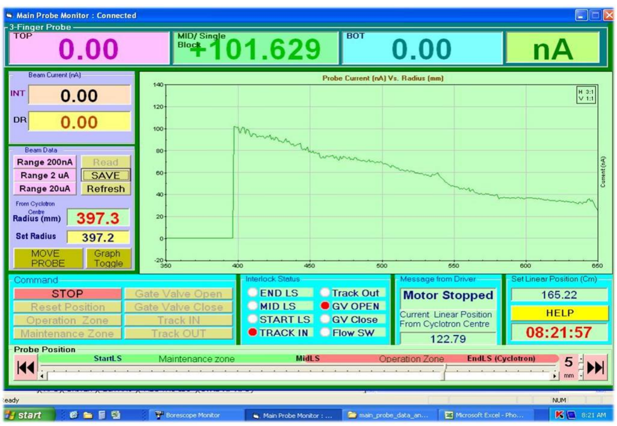

Figure 8: Ne3+ beam current variation with radius as seen on main probe control console.

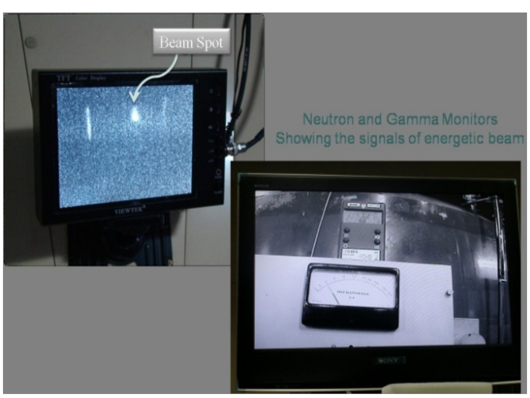

Figure 9: Beam spot on Borescope at 650 mm radius

SC cyclotron area is equipped with area neutron and gamma monitors. Neutron monitors are BF-3 based proportional counter with a paraffin moderator. Gamma Area monitors are based on GM tubes. Area neutron monitor placed near the exit port measured a neutron flux of 10 n/cm^2/sec, with Ne^{3+} accelerated beam of about 30 pnA beam current at the extraction radius with total energy of 88 MeV. A (5"x 7") BC-501A liquid scintillation was place 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 in the beam extraction direction. The following spectra show a clear evidence of neutron and gamma during operation of machine.

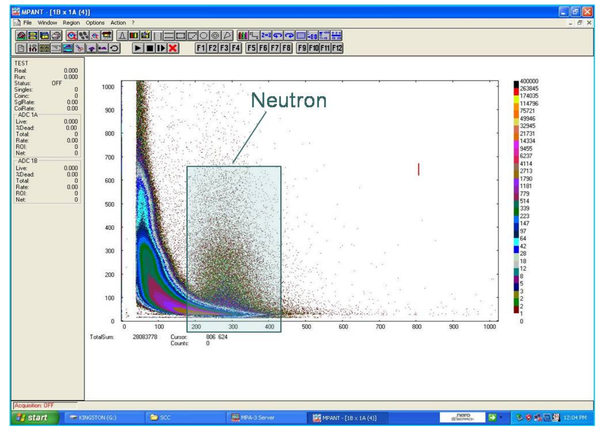

Figure 10: Neutron-Gamma discrimination with liquid scintillator.

CONCLUSION

The Kolkata superconducting cyclotron has been successfully commissioned with internal ion beams accelerated up to extraction radius producing neutrons via nuclear reactions. Shortly the beam will be extracted out of the cyclotron and transported to the experimental area for nuclear physics experiments.

REFERENCES

[1] C. Mallik, et. al., "Magnetic Field Mapping of Kolkata Superconducting Cyclotron", 18th International Cyclotron Conference, 2007, p.435.

[2] M. K. Dey, et. al., "Beam Injection System of the Kolkata Superconducting Cyclotron", 18th International Cyclotron Conference, 2007, p.346.