BEAM DYNAMICS PRIOR TO EXTRACTION IN KOLKATA SUPERCONDUCTING CYCLOTRON

S. Paul, J. Debnath, M. K. Dey, C, Mallik, R. K. Bhandari
Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata 700 064

Abstract

The Kolkata Superconducting Cyclotron has already accelerated test beams up to its extraction radius. Efforts are underway to extract the internal beam with the aid of the various extraction elements. A detailed study of the accelerated beams dynamics has been carried out to ensure that before extraction, optimum turn separation is achieved and the beam does not cross the harmful third order coupling resonance, while keeping distortions to a manageable levels. This paper discusses those results and the studies conducted.

INTRODUCTION

As in conventional AVF cyclotron, beam extraction in the Kolkata Superconducting Cyclotron will employ excitation of $\nu_R = 1$ resonance. After resonance crossing, when the beam starts precessing with the frequency $|\nu_R - 1|$ around its equilibrium position, post-resonance acceleration enables enhancement in turn to turn separation which increases the extraction efficiency. The extraction process is influenced by, among others, the internal beam quality, the measure of isochronism of the beam, and the amplitude and azimuthal position of a first-harmonic field perturbation in the extraction region. Consequently, the amplitude and phase of first harmonic needed to excite the resonance, and of those inherently present in the field have to be investigated. The study has been carried out using isochronized magnetic field based on the measured magnetic field in the median plane of the Cyclotron.

EQUILIBRIUM ORBIT

The operating diagram of Kolkata Superconducting Cyclotron in (B_0, Q/A) plane (Fig. 1) is bounded by the bending limit K_b = 500, i.e., 50 kG field at extraction, focussing limit K_f = 160, Q/A = 0.5 and B_0 = 30 kG limits. Of key importance for the beam dynamics near extraction is the behaviour of the radial betatron frequency ν_R as a function of the equilibrium orbit radius R which determines to a large extent the extraction radius. This is so because in order to obtain higher turn separation by acceleration, it is necessary to accelerate the beam into the fringe field region where ν_R drops below 1 (typically around 0.8), while ensuring that the number of turns in the fringe field is not large enough to avoid a large RF phase slip. As can be seen from Fig.2 the total radial span at ν_R = 0.8 is 0.4 inch, spanning the entire operating region of the machine. Typically the radius at which ν_R = 0.8 is reached moves inward in going from the most relativistic particles to the least relativistic ones. This is due to the main coil field pattern which shifts inward at different excitations needed for isochronising the average field.

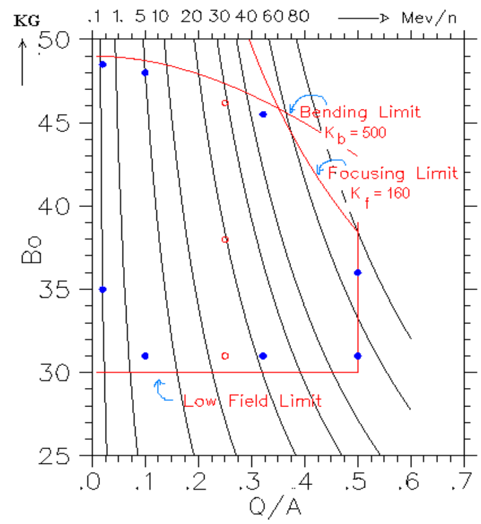

Figure 1: Operating diagram in (B_0, Q/A) plane

The tune diagram (ν_R ,ν_Z) plot for Q/A = 0.25 is shown in Fig. 3 for central field 46.5 and 31.1 kG and for energy range of a few MeV/A prior to extraction.

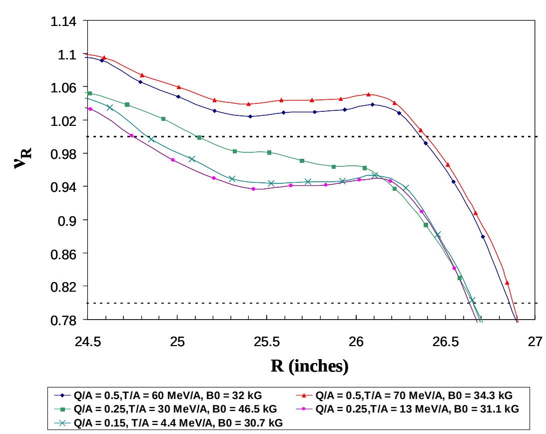

Figure 2: ν_R vs R (equilibrium orbit radius) near extraction

As can be seen, the third order coupling resonance $\nu_R + 2\nu_Z = 3$ is approached at higher values of ν_R, the lower the magnetic field, the physical reason being the increase in ν_Z due flutter increase at lower magnetic field, as is characteristic with all superconducting cyclotrons. This coupling resonance cannot be crossed in this cyclotron and the beam has to be extracted before its crossing to avoid axial blow up.

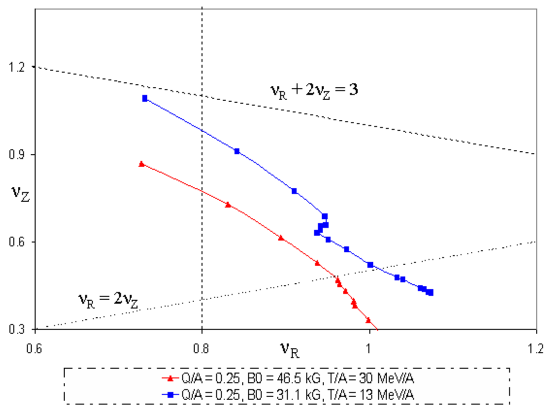

Figure 3: Tune diagram before extraction

ACCELERATED ORBIT

The process of determining the proper conditions for an accelerated beam to clear the deflector septum is an iterative one. The extraction system consists of two electrostatic deflectors, positioned in two consecutive hills, followed by eight passive magnetic channels and one active one. A number of iterations have shown that for the most relativistic particles to be extracted from the cyclotron the orbit should have a radius of at least 26.5" to 26.6" at the deflector entry.

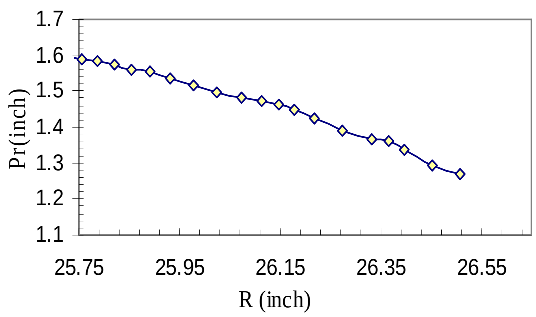

Figure 4: Radial phase plot without bump

Even at the high fields of the superconducting cyclotron (30 to 50 kG near extraction), a first harmonic of small amplitude applied at an appropriate phase will generate the radial precession needed to clear the septum of the deflector (0.25 mm thick). Figure 4 and 5 shows the radial phase plot near extraction for a test beam before and after the addition of a controlled magnetic field bump. Enhancement in turn separation (~ 0.15 inch) obtained by the addition of such magnetic bump is clearly evident.

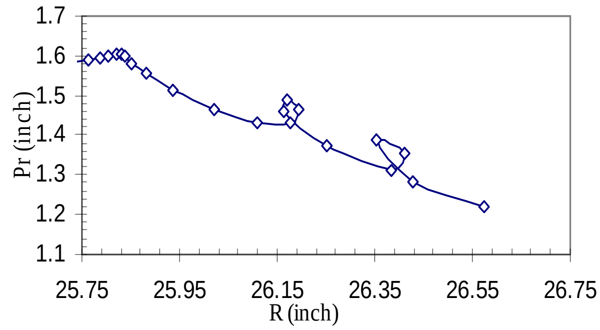

Figure 5: Radial phase plot with bump

CONCLUSIONS

The beam dynamics analysis for the Kolkata Superconducting Cyclotron shows that no difficulties should be encountered in obtaining proper beams for subsequent extraction. While many beam dynamics features are quite analogous to those of conventional AVF cyclotrons, a fundamental difference lies in the presence of $\nu_R + 2\nu_Z = 3$ resonance.

REFERENCES

[1] E. Fabrici and F.G. Resmini, Nucl. Instr. and Meth., 180 (1981) 319-333.
[2] E. Fabrici, D. Johnson and F.G. Resmini, Nucl. Instr. and Meth, 184 (1981) 301-318.
[3] M.M.Gordon and E.M. Fabrici, IEEE Trans. Nucl. Sci. NS-26 (1979) 2101.