BEAM-DYNAMICS STUDIES FOR THE PROTONTHERAPY CYCLOTRON COMET

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Calculations using the 3-D particle tracking code TRACK for the new superconducting cyclotron COMET are presented. The calculations have been performed using simulated electric and magnetic field data provided by the cyclotron manufacturer ACCEL (D).

INTRODUCTION

The general particle tracking program *TRACK*, developed at PSI [1], has been applied for the analysis of the magnetic and electric field of the new 250 MeV superconducting cyclotron for the proton therapy project at PSI [2]. The cyclotron is based on an original concept from H. Blosser (NSCL, USA) and is being designed and manufactured by the company ACCEL (Germany). Simulated 2D and 3D magnetic and electric fields were provided by ACCEL for analysis at PSI.

CALCULATIONS IN STATIC MAGNETIC FIELDS

A search has been made for the equilibrium orbits as a function of energy or average radius R_{aver} for different static magnetic fields calculated with *TOSCA*. At each equilibrium orbit, cosine and sine-like orbits in the horizontal and vertical plane were tracked, from which the 1st order transport matrix of one cyclotron sector was derived. The diagonal elements are then used to calculate the horizontal and vertical betatron frequencies ν_r and ν_z.

Some examples of ν_r - ν_z plots for different magnet-pole layouts, in which the spiral parameters of the hill were varied, are shown in Fig. 1. The aim of these studies was to search a configuration in which the ν_z=1 resonance was not reached at extraction.

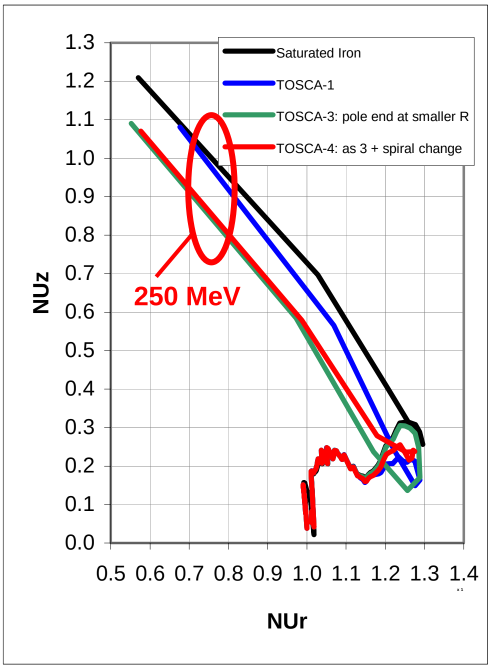

Fig. 1: ν_r - ν_z plot of different magnet-pole layouts.

Based on the calculated revolution time of each closed orbit, a study of the isochronism of the cyclotron has been made for different magnet-pole layouts. A comparison with the results of other cyclotron codes did not show any significant differences.

CALCULATIONS IN DYNAMIC FIELDS

A time dependent electric field was generated by the Micro-Wave Studio code [3]. This field was added to the static magnetic field and, starting at a radius of 9.5 cm, particle tracking was made until extraction. In Fig. 2, the energy gain per turn is shown. The shape of this curve is determined by the voltage profile along the DEEs and the phase at which the particles cross the gap (Fig. 3).

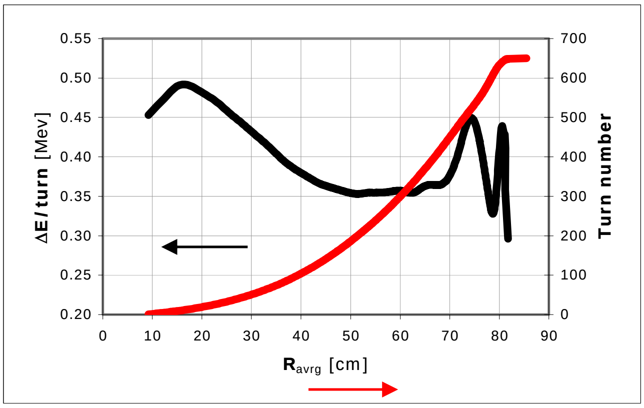

Fig. 2: The calculated energy gain per turn and turn number as a function of radius.

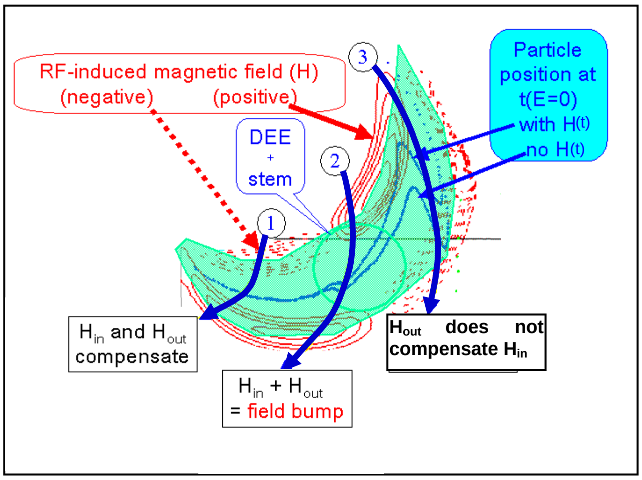

Fig. 3: Isochronism in *TRACK*: particle positions at t(Efield=0) with and without H(t) field are shown, together with three typical tracks.

In Fig. 3, the particle positions are plotted at the time when the electric field is at zero. This plot provides us with a lot of insight into the optimal frequency setting, isochronism and phase-width acceptance. Ideally this line should be in the middle of the DEE. When we also take the magnetic H(t)-field generated by the currents in the RF cavities into account, it can be seen that this results in a net kick of the phase of the particles, which grows to approximately 20 degrees (RF phase). This kick occurs mainly near the radius where the DEE-stems are located. Here (track 2) the H-fields do not cancel, which results in a small field bump of approximately $0.3.10^{-3}$ Tesla-meter. Tracks at smaller radii (track 1) experience a decrease in the total magnetic field when entering the DEE but this is cancelled by an equal increase of the magnetic field at the DEE exit. The effect of the H-field is also almost cancelled at the largest radii (track 3). Due to the spiral shape of the DEE, the H-field has a larger impact at the DEE exit than at the DEE entrance.

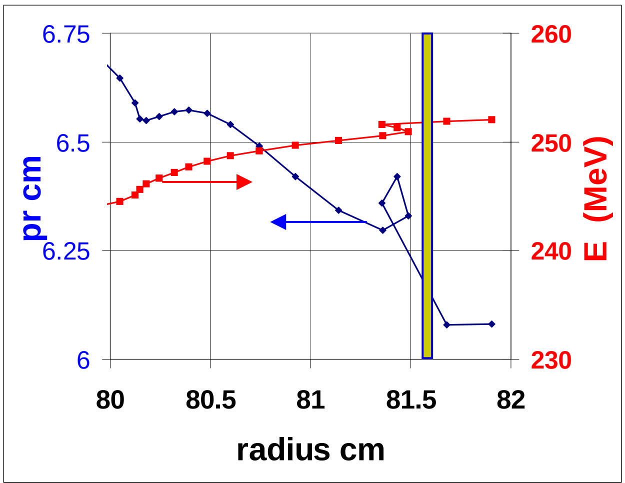

Fig. 4: Radial momentum component p_r and energy as a function of radius near extraction. The marks represent all the turns near extraction and the bar at 81.6 cm represents the extraction septum.

The example shown in Fig. 4 shows calculation results at the extraction radius. The radial momentum component p_r and energy are plotted as a function of radius near the location of the extraction septum. Using iron trim-rods located near the extraction radius, a small bump in the field has been added to excite the ν_r=1 resonance. This yields an increased orbit separation at the septum.

Fig. 5 shows the effect of the radial component of the RF field experienced by the particles, which travel between the DEE and outer liner wall after extraction. A study has been made to investigate the distortion of the tracks and phase spaces compared to tracks that have not experienced this RF field. Especially due to the spread in arrival time of the particles, there is an increase of the phase space.

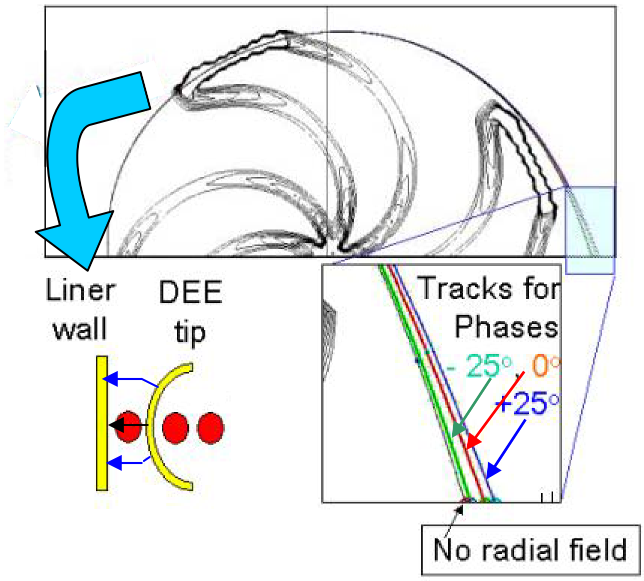

Fig. 5: Electric RF-isofield lines around the Dees and location of the extracted orbit between DEE and liner. Tracks at different phases experiencing a radial RF field in the extraction path, compared to an undistorted track.

DISCUSSION AND CONCLUSIONS

We have used the program *TRACK* successfully in the analysis of static and dynamic 3D magnetic and electric fields of a 250 MeV cyclotron. Since the program has not been written for a specific application, its command language interpreter has to be used to extract the relevant data from the particle tracks at specific locations, moments in time or at other conditions specified by the user. The calculations presented here have been done to provide an independent confirmation of the analysis made by the standard cyclotron codes used by ACCEL. Currently, we are working on detailed tracking studies in the central region and the extraction region, where we study effects due to asymmetries in the field and e.g. the coupling of resonances in the horizontal and vertical planes. These applications will make effective use of the 3D possibilities in *TRACK*.

We would like to thank ACCEL for putting the simulated fields at our disposal.

REFERENCES

[1] V. Vrankovic, D. George, *Particle Ray-Tracing Program TRACK Applied to Accelerators,* PSI Scientific and Technical Report 2001, Volume VI.

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