BEHAVIOR OF SPACE CHARGE DOMINATED BEAM ENVELOPE IN CENTRAL REGION OF HIGH CURRENT CYCLOTRON

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Abstract

In this paper the space charge effect in the two first turn after injection has been investigated. In order to determine beam envelopes, two corresponding equations were chosen. In addition, all steps of calculation were done by MATLAB program. It should be mentioned limiting current and also magnetic, electrical field and edge effect has been considered. As far as, the high current cyclotron with 0.8π mm mrad emittance has been studied and current alters till 10 mA.

INTRODUCTION

In this paper, the space charge and beam envelope in the two first turn was investigated. And also specification of an IBA cyclotron -CYCLONE30 HC- which has four sectors, two delta type resonators and mulicaspe ion source was considered. At hill center the maximum and average magnetic field are 1.7 T and 1.03 T, respectively. The ion source produces proton beam with 30keV energy and 15mA current, and in next a sinuousal buncher bunches this beam. Finally, the beam is injected axially into the inflector.

More serious effect of space charge is defocusing along with injection. Moreover, weak vertical focusing causes an increase beam envelope. In order to compute the space charge is dominated by beam envelope, the K-V (Kapchisky - Vladimirsky) equation was used. Beam envelope oscillation has been investigated by the variation of beam current and Dee voltage.

DISCUSSION

Beam envelopes are represented by couple Eqs. 1,2 where X(s) and Y(s) are the beam envelopes in x-z plane and y-z plane respectively, and s is the distance along the equilibrium orbit [1]:

$$X'' + k_x - \frac{2K}{X+Y} - \frac{\varepsilon_x^2}{X^3} = 0 \tag{1}$$

$$Y'' + k_y - \frac{2K}{X+Y} - \frac{\varepsilon_y^2}{Y^3} = 0 \tag{2}$$

k_x, k_y are the periodic focusing strength of magnet with the period N. These quantities are equal to $\frac{v_r}{\rho}$ and $\frac{v_z}{\rho}$, respectively where ρ is the radius curvature of particle and K is the generalized perveance which is obtained from Eq. 3.

$$I = \frac{I_0}{2}\beta^3\gamma^3 K \tag{3}$$

where I_0 is the characteristic current which is defined as $I_0 = 4\pi\varepsilon_0 mc^3/q$. β and γ are usual relativistic terms.

The important values which have been used in simulation are shown in Table 1.

Table 1: Main Parameters used in Simulation

Injection energy	30 keV
Dee voltage	50 kV
Hill angle in central region	54 °
Valley angle in central region	36 °
Emittance	0.8 πmm mrad

In order to study the behavior of a beam passing through each bending magnet (dipole), we assumed the magnets as thin lens so the focal length of the thin lens could be obtained by the following formula (Eq. 4):

$$f = -\frac{\tan\alpha}{\rho} \tag{4}$$

where α_1 is the entrance angle to hill and α_2 is the exit angle from hill.

The exit angle from hill is equal to the entrance angle to valley and entrance angle to hill is equal to exit angle from valley, but these angles vary before and after the boundary field. The flaring and edge effects are noted when the beam passes from the boundary of bending magnet, and in this article these effects have been applied by using thin lenses. Since the thin lens does not change the beam radius, so the beam motions can be predicated according to the transfer matrices [2]. A linear decreasing field is considered in order to simulate fringe field in simulation. The fringe field changes the optics of the dipole and causes oscillation in the beam trajectory around the mean orbit.

$$\begin{pmatrix} x_2 \\ x'_2 \\ y_2 \\ y'_2 \end{pmatrix} = M \begin{pmatrix} x_1 \\ x'_1 \\ y_1 \\ y'_1 \end{pmatrix} \tag{5}$$

where

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$$M = M_{edge} \cdot M_{dipole} \cdot M_{edge} \qquad (6)$$

In Eq. 5 arrays in matrices with subscript 1 and 2 represent the initial and final points respectively. These matrices are different for hill and valley, where x is horizontal and y is vertical motion, and elements with prime are gradients that relatives to orbit and show the slope of trajectory.

$$M_{dipole} = \begin{bmatrix} \cos\varphi & \rho\sin\varphi & 0 & 0 \\ -\frac{1}{\rho}sin\varphi & cos\varphi & 0 & 0 \\ 0 & 0 & 1 & S \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (7)$$

$$M_{edge} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ \frac{\tan\alpha}{\rho} & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & -\frac{\tan\alpha}{\rho} & 1 \end{bmatrix} \qquad (8)$$

Where φ is the angle of turning of orbit, and S is the length of the bending magnet. All parameters of these two matrices such as ρ, α, φ and S are different for hill and valley. S can be obtained by multiplying the radius curvature of the particles by the angle of turning of orbits $S = \varphi\rho$.

In order to achieve worth results from simulation it should be considered that when a beam passes through the acceleration gap, the energy of the beam will increase. Since γ is the function of beam energy, these two values should be changed after passing each acceleration gap.

Equations 1 and2 were solved numerically by Runge-Kutta method on MATLAB program. Totally the results show the envelope of beam has decreased after passing through the acceleration gap. We have applied the method which an article had used for optimization [3].

It is worth mentioning that when the value of beam current (I=0) and Dee voltage are zero, zero beam current means the space charge term is overlooked. As it is shown in Fig. 1, the beam envelopes are periodic and the maximum amplitude is limited to 2.55mm and 2mm in X-plane and Y-plane, respectively. Since acceleration voltage is zero, variation of the beam energy would be zero, too.

In Fig. 2 the Dee voltage is not zero and because it leads increasing in the energy of beam after the beam passing each accelerating gap as a result, it is not periodic any more.

Figure 3 shows the high beam current leads increasing the envelope of beam. And the initial conditions are changed and new ones are matched to new beam trajectory.

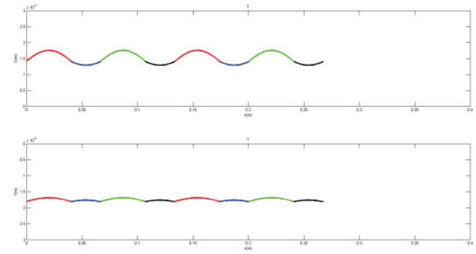

Figure 1: Beam envelopes in two directions (radial and vertical) along equilibrium orbit with zero beam current and no acceleration.

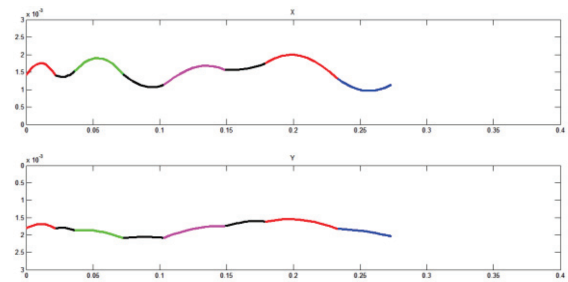

Figure 2: Beam envelopes in two directions (radial and vertical) along equilibrium orbit with zero beam current and 50 keV dee voltage.

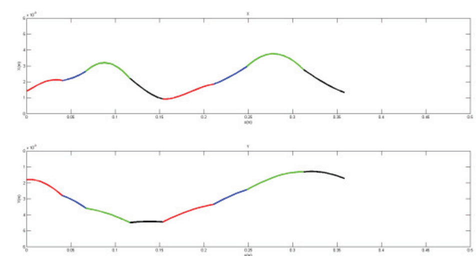

Figure 3: Beam envelopes in two directions (radial and vertical) along equilibrium orbit with 17mA beam current and 50 keV dee voltage.

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