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SPACE CHARGE EFFECTS IN THE VERTICAL PLANE DURING INJECTION IN A SYNCHROCYCLOTRON

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Abstract

The evolution of the beam during capture time is followed by means of numerical methods. The space charge field is obtained by constructing, for purposes of calculation, a rectangular network in the beam. All particles of a given parallelepiped are replaced by a single macroparticle of equivalent charge placed at the centre of the parallelepiped. The field produced by all the macroparticles is then calculated at the knots of the network. The field at any other place is found by interpolation. Beam shapes and distribution of particle densities have been calculated in this way for the CERN synchrocyclotron, at various instants in the vertical plane . The mean accelerated current is calculated.

Introduction

The limitation of the accelerated current in a synchrocyclotron is due mainly to space charge. Most of the time, the infinite sheet approximation is used to calculate the space charge field. In this paper, a more accurate method independent of the beam shape and of the particle density is used.

I. Method of calculation

The computer programme is that used for studying the filling of the phase space without space charge [1] : we draw at random some of the initial phases of the extracted particles at each period of the R.F. field, and integrate the equations of motion of these particles with a step of half a turn. By means of projections, beam shapes and distribution of particle densities can be obtained in phase, median and meridian planes.

II. The space charge force

We consider only the axial component of the space charge force. At each step of integration, we construct a rectangular network in the beam. We choose the number of parallelepipeds used ; the dimensions of these parallelepipeds are then determined, at each step, by the height, the radial and azimuthal spreads of the beam. The field at the knots of the network is calculated by replacing all particles of a given parallelepiped by a single macroparticle of equivalent charge placed at the centre of the parallelepiped. The field which acts on a particle is found by interpolation.

III. Parameters of the central region

The central geometry considered here is of the "closed" type (calutron source and cones) and has been studied in detail by Comiti and Giannini [2]. Let us give briefly some parameters of the CERN improvement programme [3]. The magnetic field at the centre is set at 1,97 Tesla. The parameter K_o, which defines the shape of this field, is nearly constant and equal to 2. The cosine of the synchronous phase is chosen so that the capture time should be optimum, i.e. $\cos\phi_s = 0,133$. The R.F. voltage has a value of 30 kV and the frequency versus time programme is linear, at least in the considered region. The repetition rate is set at 500 Hz.

IV. Results

IV.I. Mean accelerated current

Figure 1 represents the mean accelerated current versus the injected current. In the case (a) (without space charge), the dependence between the two currents is linear, while in presence of space charge (b), the mean accelerated current is rapidly approaching an intensity limit. Here this limit is 21 µA, in good agreement with the value measured at CERN [4]. The maximum current is reduced by a factor 2,5 which shows the importance of the space charge effect.

IV.II. Beam profile in the vertical plane

Figures 2 and 3 represent the particle density in the z, r plane at the beginning of injection. In Figure 3, space charge force is considered, while in Figure 2 it is not. These figures were obtained by projecting on the z,r plane the coordinates of all particles making up the beam. The z,r plane has been divided in elementary rectangles, the size of a rectangle being given by the space line and the space column of the printing machine ; a symbol indicates the number of particles which are projected in each elementary rectangle of this plane *.

In Figure 2 the defocused particles are only electrically defocused, while in Figure 3, there is a "blow up" due to space charge and many particles are lost by striking the cones or the dees.

Conclusion

We have studied, by means of numerical procedures, the space charge effects in the vertical plane during injection. We have calculated the mean accelerated current. The agreement with the measured current at CERN is very satisfactory. The effect of the space charge on the beam profile has also been shown.

Acknowledgments

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References

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* If the number of particles which are projected in an elementary rectangle is lower or equal to 9, the symbol is the corresponding digit. If this number is greater than 9, the following convention is used : A = 10, B = 11, ..., Z = 35, $ for numbers greater than 35.

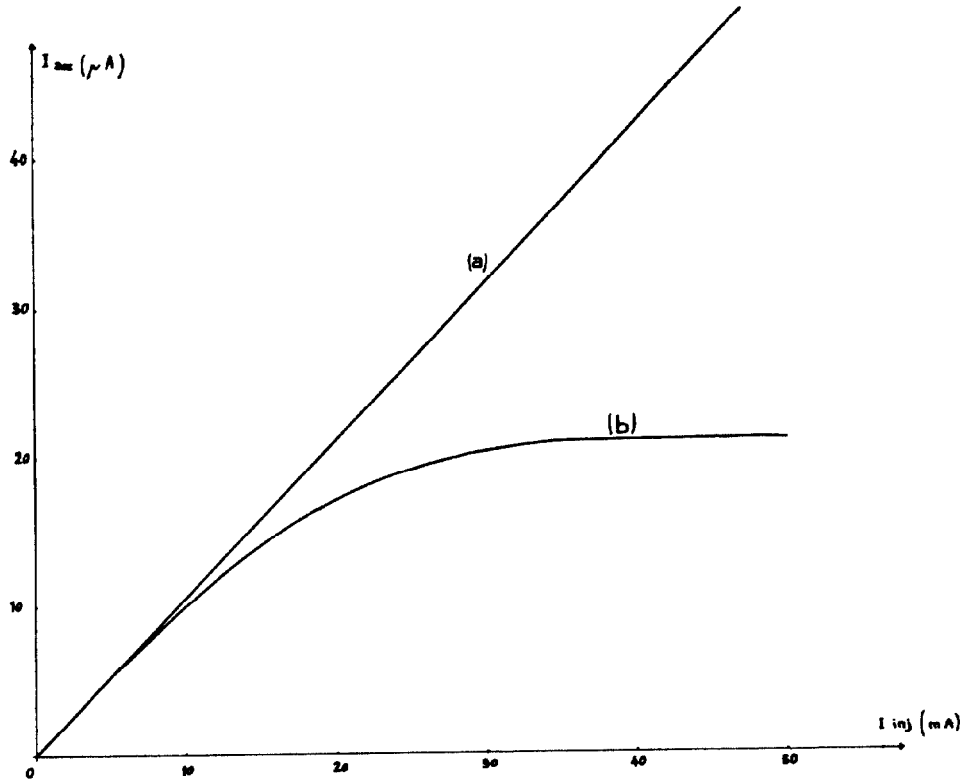

Figure 1 : Mean accelerated current versus injected current
a) without space charge
b) with space charge

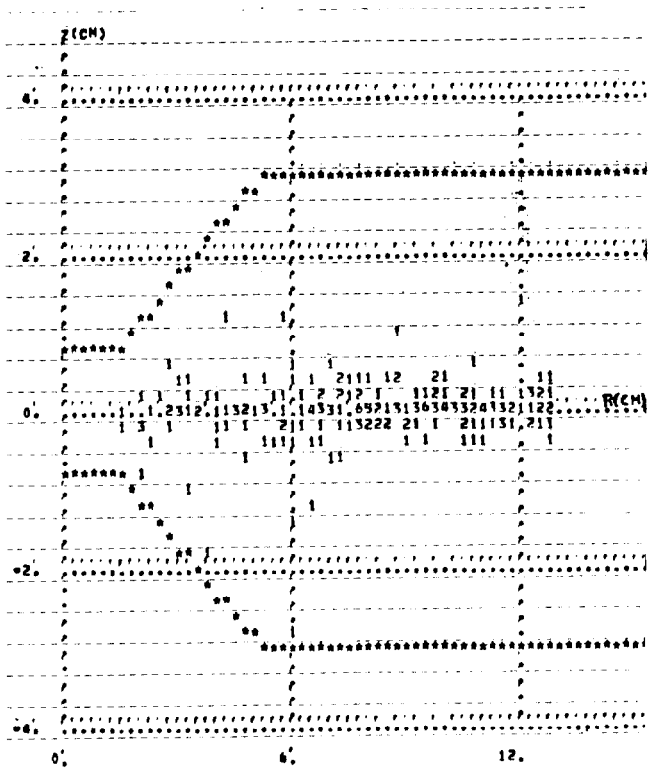

Figure 2 : Beam profile in the z-r plane without space charge (3 particles are drawn per period)

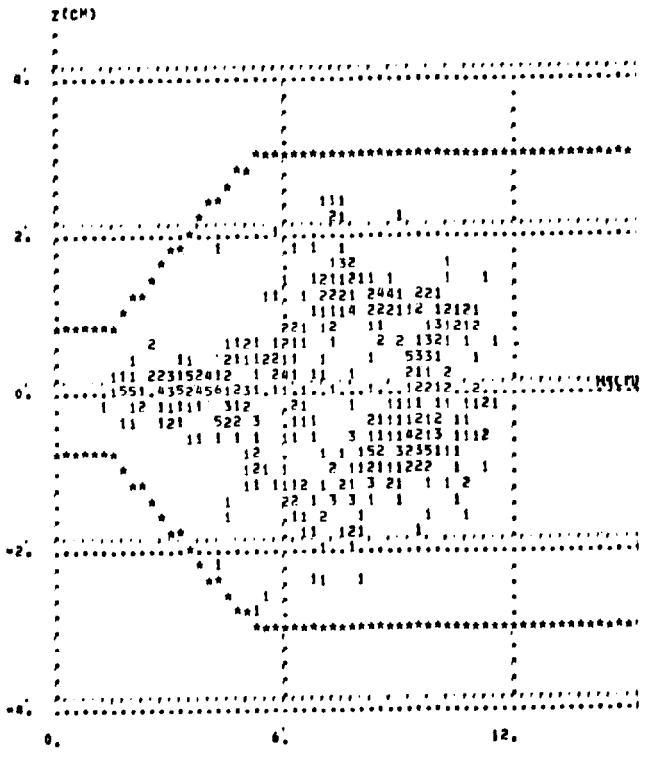

Figure 3 : Beam profile in the z-r plane with space charge (12 particles are drawn per period).