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

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Abstract

Numerical methods have been used to study the influence of space charge on the filling of the energy-phase plane during capture time. Axial and azimuthal space charge effects have been studied separately. Beam shapes and distribution of particle densities have been calculated for the CERN synchrocyclotron and the population of the energy-phase plane has thus been determined as a function of time.

Introduction

One of the major difficulties in studying the beam motion in a synchrocyclotron is the calculation of the space charge forces. Indeed, the equations of motion cannot be easily solved, because of the unknown distribution of particle densities. Most of the time, the infinite sheet approximation is used. In order to study more accurately the space charge effects, we have used a numerical method of calculation which offers the following main advantages :

a) No assumption is made as to the beam shape or particle density

b) A great number of particles is used to represent the beam. Thus the results are statistically justified.

Space charge effects have been studied in previous papers [1,2]. Here only space charge effects in the energy phase-plane will be considered.

A - METHOD OF CALCULATION OF SPACE CHARGE FIELDS

In order to calculate the axial and azimuthal components of the space charge force, the following method was used : at each step of integration, we construct rectangular networks in regularly spaced cross-sections of 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. In our method :

1) The network is, at each instant, matched to the beam dimensions.

2) The calculation is done in two steps : the first one consists in calculating the field components at the knots of the network and the computation time does not depend on the number of particles considered in order to represent the beam. The computation time of the second step (interpolation used to calculate the effective fields) is proportional to the number N of particles.

The classical method, i.e. calculating space charge fields which act on each particle by means of Coulomb's law, would require a computation time proportional to N^2. In order to keep the computation time reasonable, only a few hundred particles are usually considered. With our method, more than 20000 particles can be considered and their motion followed during about 1000 turns.

B - RESULTS

Figures 1,3,5 represent the particle density in phase space, without space charge. These figures were obtained by projecting on the phase plane the coordinates of all particles making up the beam. The phase plane has been divided in elementary rectangles, the size of a rectangle beeing 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. (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).

In Figures 2,4,6 we have superposed two figures : above, the phase plane, considering only the axial field, and below the phase plane including the azimuthal field. At the beginning of injection (Fig. 2) many particles are lost due to axial space charge. The extension of the ring is narrowed as the phases between 0° and 30° are defocused from the

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start. The percentage of accelerated particles which was equal to 53% without space charge decreases down to 27%. As to azimuthal space charge, it creates a slight spread in phase, but the number of accelerated particles is nearly the same.

When the particles reach the minimum radius (i.e. the phase 90° for the second time) (Fig. 3,4), the azimuthal space charge induces new losses. On the other hand, the total number of particles is the same, therefore there are fewer defocused particles. This may be explained by the fact that azimuthal space charge increases the phase width. The particle density is then smaller and the axial space charge force becomes weaker.

After the capture time (Fig. 5,6), the effects of the azimuthal space charge force become more pronounced. The oscillation period of the particles, which was equal to 7,40 μs (without space charge) becomes equal to 8,50 μs.

The capture time is also perturbed. It decreases slightly, and the range of accelerated phases decreases also from 60° to 30° under the influence of space charge.

Conclusion

By means of numerical procedures we have studied the beam motion in a synchrocyclotron. The filling of the phase space is perturbed by the space charges forces. The particle density is no more uniform , "holes" appear due to particles losses. Furthermore the range of accelerated phases is reduced to half of its value. The capture time is also diminished whereas the oscillation period increases when the azimuthal field is considered. Many more details can be found in Ref. 2.

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References

1. D. Thouroude, Particle Accelerator Conference, San Francisco (5-7 Mars 1973). (I.E.E. Transactions on Nuclear Science)
2. D. Thouroude, CERN Report MSC/PR/3995 (1975).

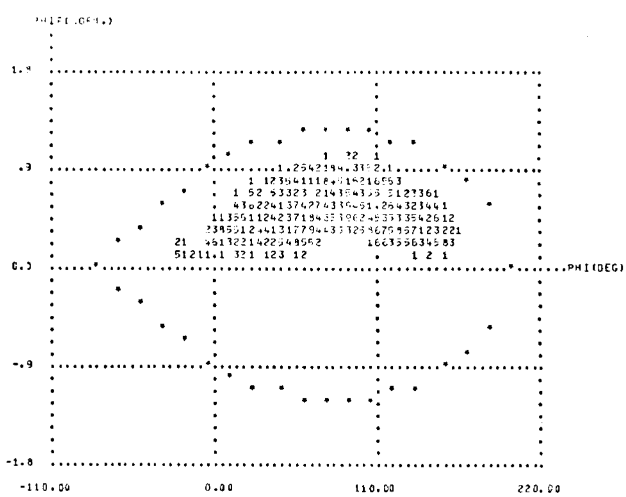

Fig. 1 Phase plane at the beginning of injection (without space charge)

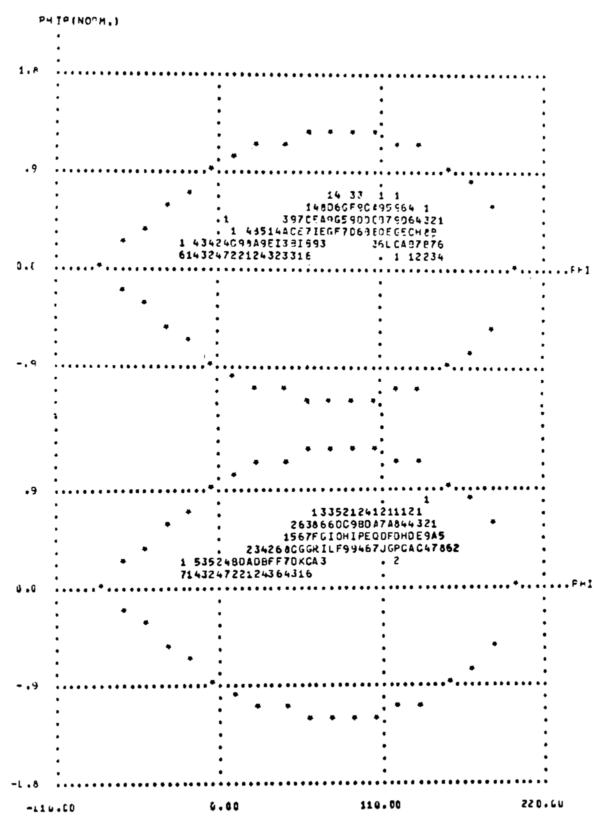

Fig. 2 Phase plane at the beginning of injection (above: axial space charge; below: axial and azimuthal space charge)

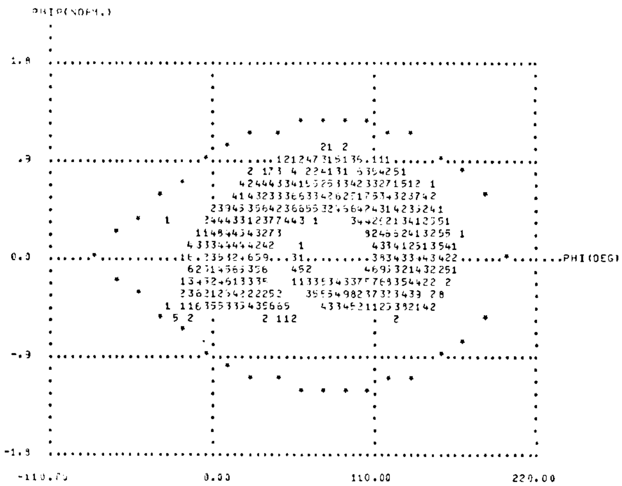

Fig. 3 Phase plane after one oscillation period (without space charge)

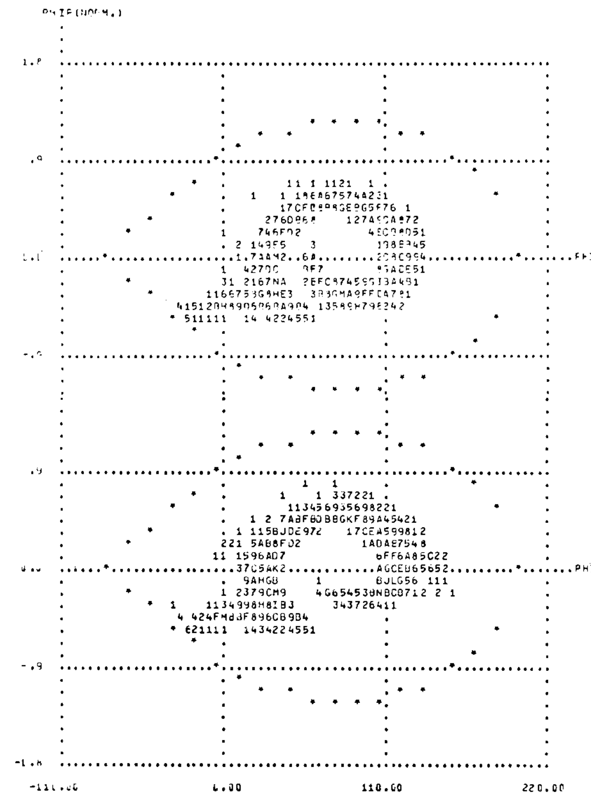

Fig. 4 Phase plane after one oscillation period (with space charge)

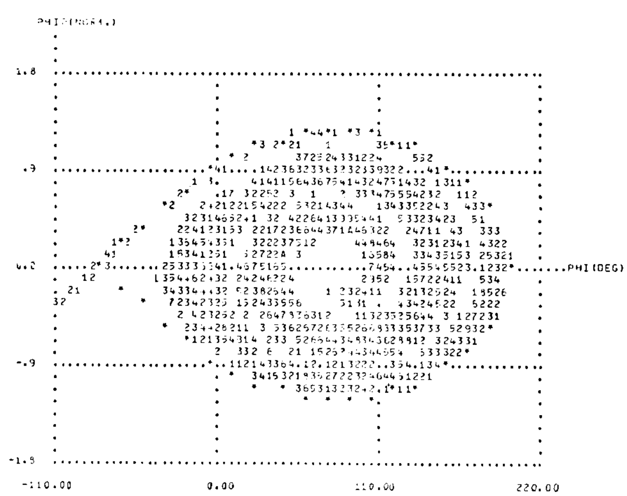

Fig. 5 Phase plane after capture time (without space charge)

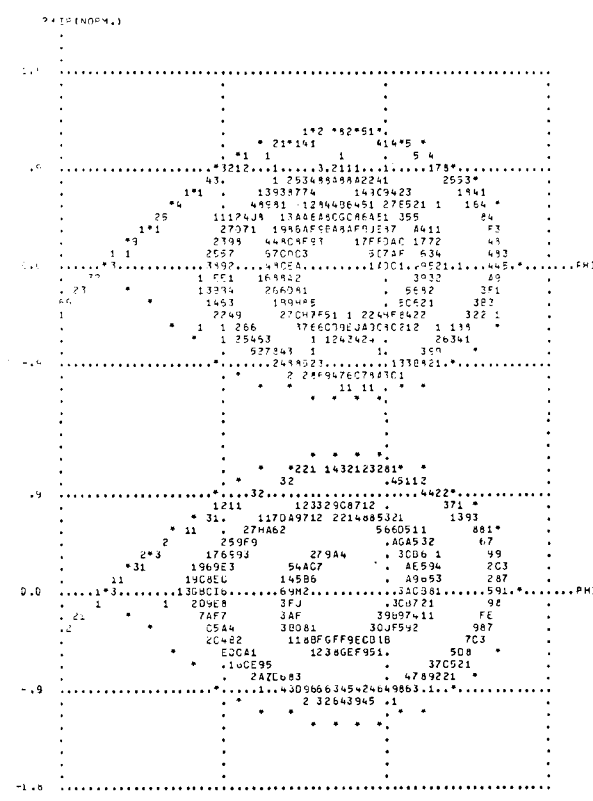

Fig. 6 Phase plane after capture time (with space charge)