

THE INFLUENCE OF NON-LINEAR COULOMB FORCES ON DISTORTION OF CONFIGURATION OF A BEAM PHASE VOLUME

V.S.Kuznetsov, G.I.Trubnikov, N.P.Kuznetsova, R.P.Fidelskaya

D.V.Efremov Scientific Research Institute of
Electrophysical Apparatus, Leningrad, USSR

Abstract

The reasons are discussed which cause the distortions of the beam phase volume configuration. The results of numerical calculations for the phase density redistributions under the influence of the Coulomb forces for some accelerating and focusing systems are given.

Regularities of the increase of the effective phase volume in accelerating and transporting a beam are considered. The dependence of distortions of the phase volume configuration on the initial phase density distribution is investigated.

Introduction

In high current d.c. accelerators used as linear accelerator injectors one of the most important characteristics is the value and configuration of the transverse phase volume. In Ref.1-3 it has been shown that in real beams affected by nonlinear Coulomb forces, variations of the configuration of the transverse phase volume take place.

In the present paper results are given of a number of numerical experiments conducted for the purpose of finding out the basic properties and regularities of the growth of the beam effective phase volume in accelerating and transporting systems of d.c. accelerators. Generally, to investigate beams with non-stationary distribution of phase density both discrete^{4,7} and continuous^{1,8,9} calculation methods are used. In our investigations the continuous calculation method was used. This method allows to obtain such important characteristics of the beam as phase density distribution, configurations of cross-sections and projections of transverse phase volume, current density distribution etc.

As a result of these numerical experiments some basic principles of construction of accelerating and transporting systems, providing minimum distortions of the transverse phase volume, have been found and formulated.

Beam transport in a periodic focusing system

To investigate the redistribution of the phase density and distortions

of the transverse phase volume configuration in the transport system, a periodic focusing system commonly used has been chosen. Parameters of this system have been chosen from calculations, made in microcanonical approximation¹⁰. In the general case there exist two solutions for the periodic system: strong focusing, when the ratio R_{max}/R_{min} is large and weak focusing when R_{max}/R_{min} is small (R_{max} is the beam radius in the thin lens plane, R_{min} is the beam radius in the crossover). The results of numerical calculations are given in Fig.1 - for the case of weak focusing and in Fig.2 - for the case of strong focusing. In the initial cross-section in both cases the beam with the Gaussian-Maxwellian distribution of the phase density was taken. The energy beam was 600 KeV. In the present and subsequent experiments the beam of 650 mA and normalized emittance of π cm.mrad was calculated.

From Figs. it is seen, that in the case of strong focusing the distortions of the phase volume configuration are much greater. Also, with strong focusing the motion of the beam charged particles through the focusing system is unstable.

Fig.3 shows the growth of the effective emittance for the calculated cases. Thus, the present numerical experiment shows, that the distortions of the phase volume configuration and the growth of the effective emittance are much greater in the system, using strong focusing.

Accelerating systems

Accelerating systems, used in d.c. accelerators, can be divided into two groups: systems with prefocusing and systems without prefocusing.

The system with prefocusing is applied in existing preinjectors of proton synchrotrons of the Institute of High Energy Physics and the Institute of Theoretical and Experimental Physics. In this system the main part of the charged particle flight-time through the accelerator is the flight-time through the prefocusing system at low energy.

In the system without prefocusing the particles, coming from the ion source, come at once into the accele-

rating field and are then focused at full energy.

Calculation results of the phase density redistribution for the discussed systems are given in Figs.4 and 5. Fig.4 gives the beam motion in the system, similar to that operating in the Institute of High Energy Physics but reduced in half. The average strength of the accelerating field is 18 kv/cm. Fig.5 shows the motion of the beam with the same initial parameters in the 18 kv/cm uniform field.

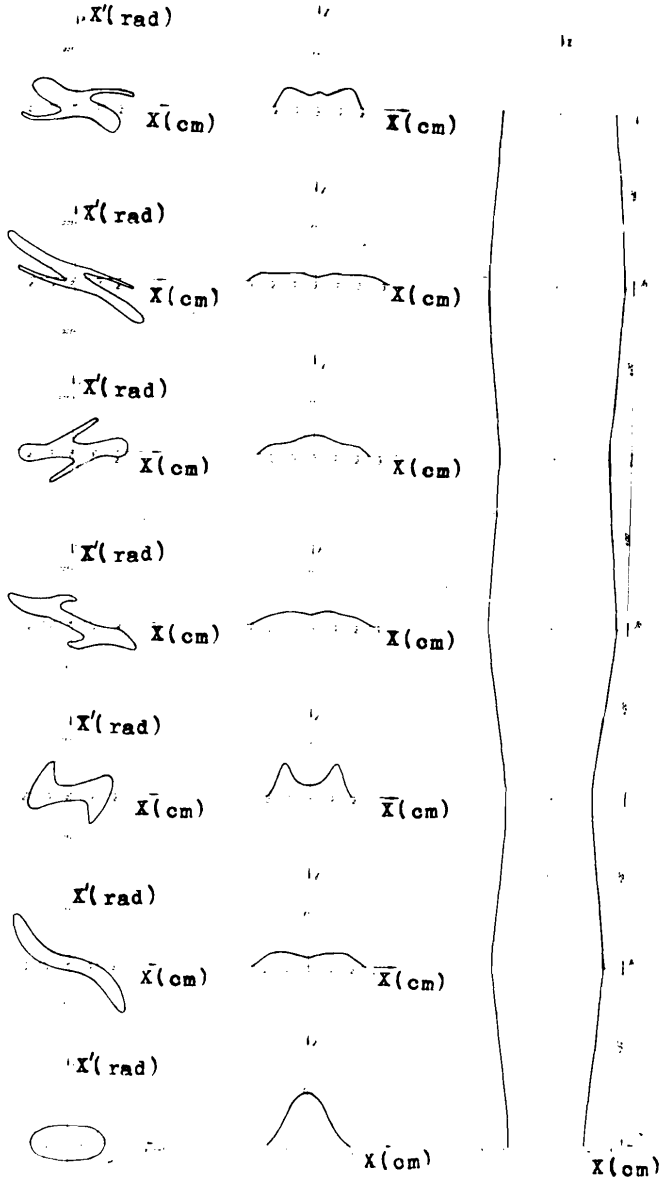


Fig.1. Envelope, current density distribution and projections of transverse phase volume for the beam focusing by a periodic thin lens system (weak focusing)

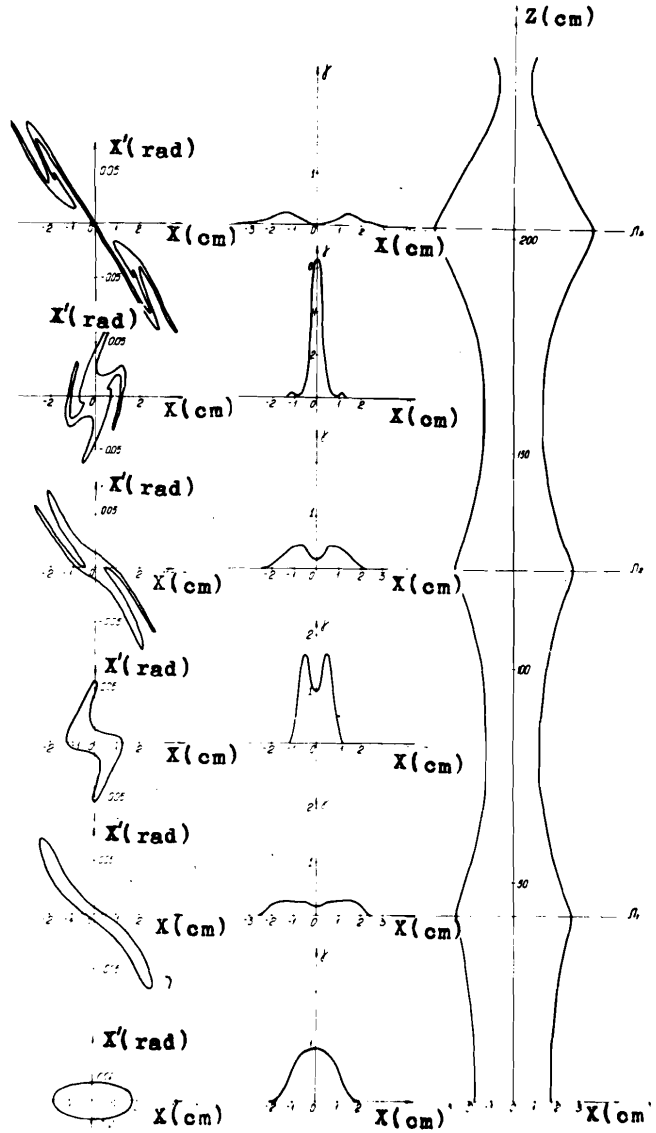


Fig.2. A periodic thin lens system (strong focusing)

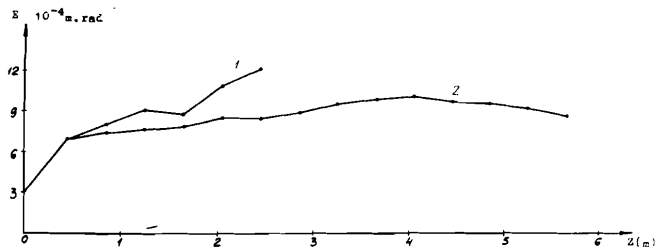


Fig.3. The growth of the effective emittance of the beam focusing by a periodic thin lens system. 1 - strong focusing; 2 - weak focusing

As is seen from Figs. in the system with prefocusing, characterized by the larger flight-time, the distortions of the phase volume and the growth of the effective emittance are much greater, than in the system without prefocusing.

Dashed lines in Fig.5 show the calculation results of the motion of the beam, whose initial distribution of current density in the diameter is uniform and Coulomb forces at the initial moment are linear. The results of this numerical experiment show that because of thermal velocity spread the given current density distribution is not preserved and becomes non-uniform. This results in the initiation of non-linearity of Coulomb forces and, respectively, in the distortions of the phase volume configuration. In this case the value of the phase volume distortions is roughly the same as with the non-uniform initial distribution of current density.

Fig.6 gives the calculation results of the beam motion in the system without prefocusing and with subsequent strong focusing; its phase volume value is both zero and finite. In first case the projection of phase volume is described by a line. As is seen from Fig. the distortions of the phase volume line repeat in general the distortions

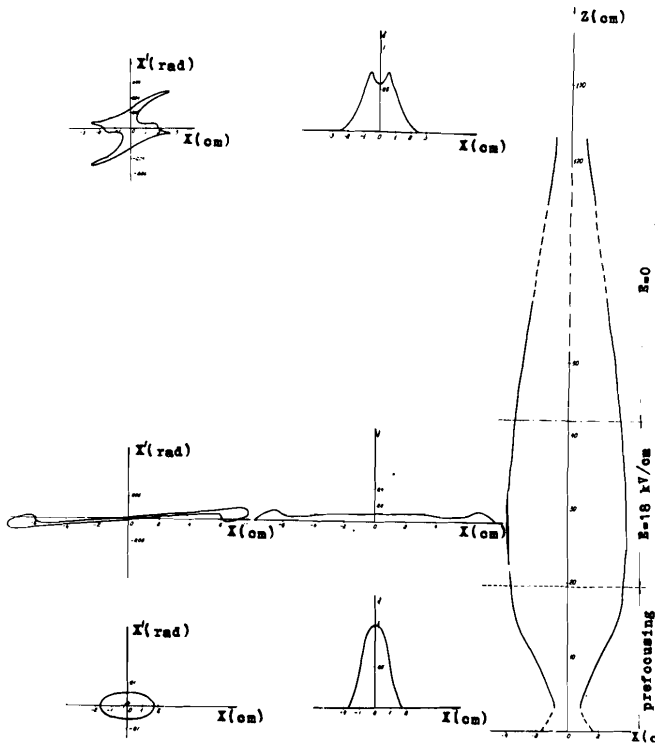


Fig.4. Accelerating system with prefocusing

of the configuration of finite phase volume, represented by a dashed line. Circumscribing around this line an ellipse with the least area, one can speak about the finite value of effective emittance even in the case of zero velocity spread of particles. Thus, the present experiment permits to draw the following conclusions.

Firstly, it shows, that even the beam with negligible thermal velocity spread under the action of nonlinear Coulomb forces will occupy the finite effective volume in space XX^1 .

Secondly, it suggests the possible method of investigation of the Coulomb forces by means of calculating the beams with zero phase volume, which can be realized much easier.

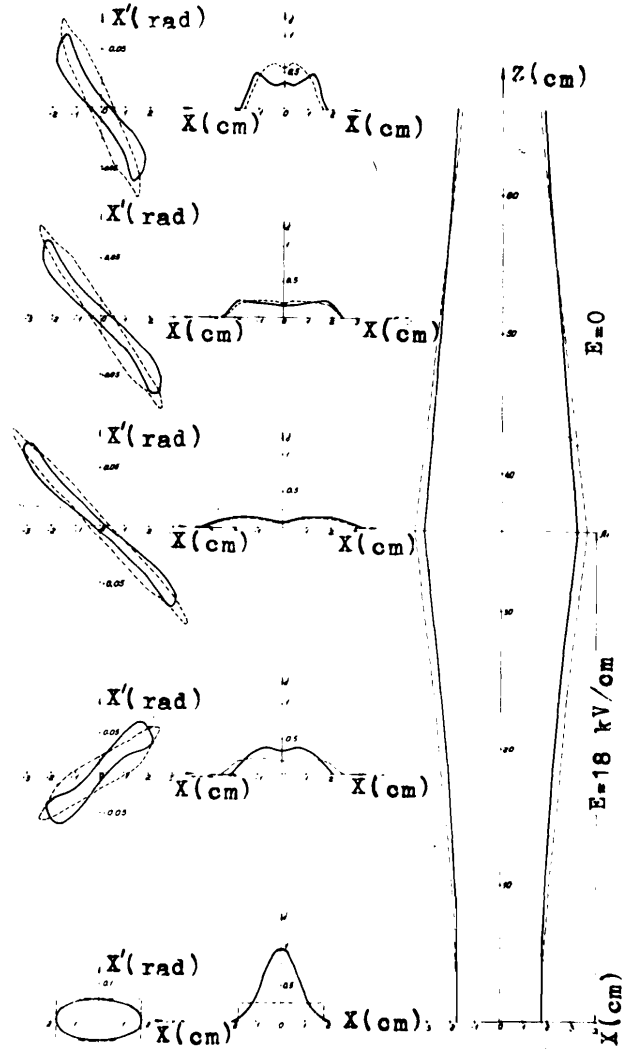


Fig.5. Accelerating system without prefocusing. Solid line-initial current density is gaussian, dashed line-initial current density is uniform

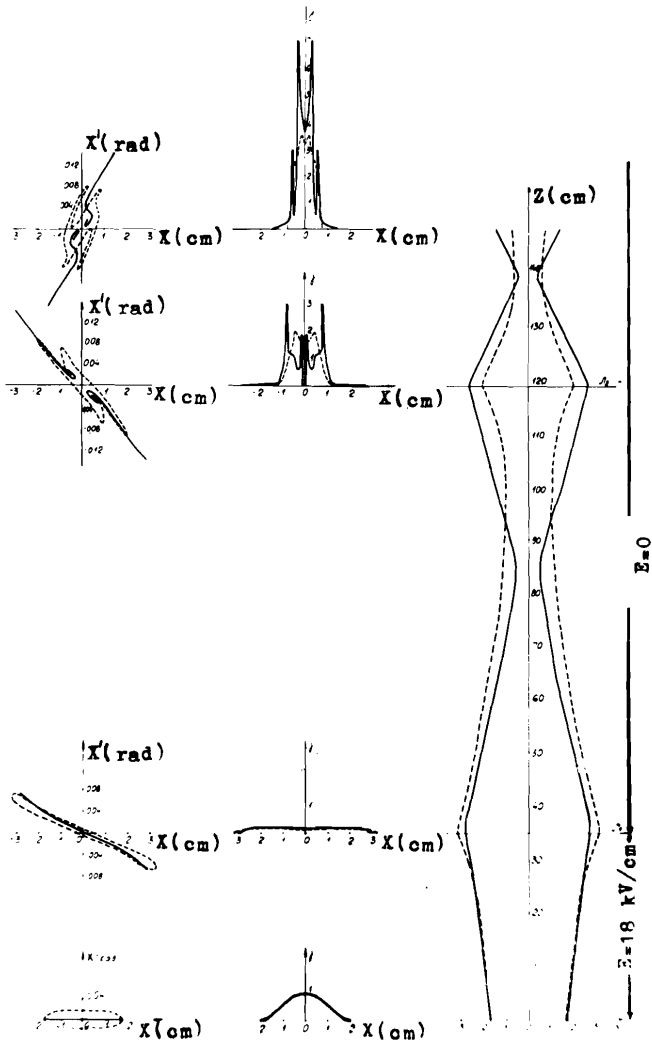


Fig.6. Acceleration without prefocusing. Solid line - $V_4=0$; dashed line - $V_4 \neq 0$

Conclusion

Numerical experiments conducted on investigation of processes of the phase density redistribution make it possible to draw the following conclusions.

1. When accelerating and transporting the beam its quality, effective phase volume and current density distribution depend strongly on the effect of nonlinear Coulomb forces.

2. When transporting the beam the weak focusing system is preferable because strong focusing results in the substantial distortions of the phase volume configuration and the rapid growth of effective emittance.

3. The accelerating system without prefocusing, characterized by the

small time of flight, exhibits the similar advantage.

4. The effect of nonlinear Coulomb forces depends weakly on the initial distribution of current density.

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