SIMULATION OF THE INITIAL PART OF A HIGH-CURRENT PROTON ACCELERATOR WITH FOCUSING BY AN ELECTRON BEAM

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In this work it is simulated the proton acceleration with current of 0.1...0.6 A, energy up to 3 MeV. In this case the parameters of focusing electron beam are varied in the following limits: the current is 40…100 A, energy 100 kV, intensity of focusing magnetic field 2…3 kOe. The efficiency of proton capture to the acceleration process has been calculated as up to 99%.

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1. INTRODUCTION

In the recent time, practically in all intense linear proton accelerators (developed for energy 1 GeV and mean current 100 mA, e.g., see [1]), the initial part of acceleration (IPA) is based on the RFQ principle that proposed by I.M. Kapchinsky and V.A. Teplyakov [2]. Besides, a project of accelerator with 1 GeV energy and 250 mA mean current was developed where the proton transverse focusing by superconducting magnetic fields had been proposed [3]. In Ref. [4] it was discussed the possibility of an intense linear proton accelerators with current up to 1 A, using the IPA with the radial focusing by an intense electron beam. It is ought to mark that proton focusing by electron beam firstly was theoretically investigated in [5] and experimentally tested in [6]. But to the recent time the systematical studies of this method was not carried.

The presented work that continues [4], is devoted to investigation of main peculiarities of focusing and acceleration of an intense proton beam from 100 keV to 3.0 MeV using transverse focusing by the electron beam space charge.

2. ACCELERATING PARAMETERS AND METHODOLOGY OF SIMULATION

The main parameters of the initial accelerating channel are as follows. The phase-focusing and accelerating channel consists of cylindrical RF electrodes (drift tubes) divided by accelerating gaps. The RF frequency is 152.5 MHz. The RF amplitude is varied from 12.8 kV at the channel input to 76.8 kV at the channel output; accordingly, the accelerating gaps are varied from 3 mm to 10 mm. The channel aperture is 7 mm. That channel can be realized as an IH-resonator with the π-wave accelerating mode. There are two sections with 44 and 84 RF accelerating periods. The channel length is 4.75 m. The input proton energy is 0.1 MeV, the output one is 3 MeV.

The focusing electron beam has energy of 100 keV, current 15…100 A, and radius 1…2 mm. The electron beam was magnetized by an external longitudinal magnetic field with intensity of 2…3 kGs. In this case, for preliminary simulations of proton dynamics, the electron beam was considered as a non disturbed long cylinder with uniform density.

The simulation of the proton beam dynamics was executed with account of its space charge. It was used the PIC method with Coulomb mesh 64x32x32. The amount of the macroparticles was 10000 or 25000.

3. RESULTS OF SIMULATIONS

At the accelerator input the proton beam parameters were as follows: proton radii 0…0.5 mm, angles ± 60 mrad, energy scatter 0.5…5%, the transverse RMS emittance 0.50 mm·mrad; for proton energy scatter of 0.5 % the longitudinal RMS emittance is of 0.70 mm·mrad.

The non disturbed beam electron density was $4\cdot 10^{11}$ cm^{-3}. The electron beam current was varied from 43 A to 75 A accordingly to variation of proton beam current from 100 mA to 600 mA. In this case, proton losses are less than 1%.

The proton beam emittance is shown in Fig.1 in plot of its input current. The curve $\varepsilon_\perp$ (top) corresponds to the RMS emittance on the xx' plane, and the curve $\varepsilon_\parallel$ (bottom) corresponds to the RMS longitudinal emittance $\Delta z \Delta\beta_z$.

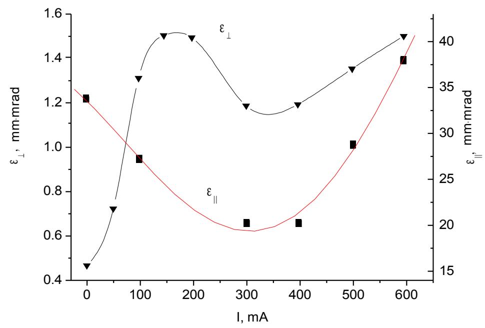

Fig. 1

These curves have the minimum for proton beam current 300…400 mA. This dependence can be explained by the process of adiabatic bunch forming for different proton currents, as it is presented in Figs.2-4.

In Fig.2,a it is shown the phase portrait in the longitudinal plane for the case of weak proton current. The correspondent non uniform proton density distribution is shown in Fig.2,b. In Figs.3,3,a and 4,4,a are presented analogues results for proton beam currents of 200 and 300 mA. One can see the formation of a dense core with a rare halo in the case of 300 mA current.

In Fig.5 it is shown the intensity of the longitudinal Coulomb field (in kV/cm) on the axis of 28-th accelerator period (for the proton current of 100, 300 and 500 mA). Here K_z is the Coulomb cell number; K_z=33 corresponds to the bunch center.

The above mentioned results show that the phase-focusing and formation of proton beam with current <150 mA is accompanied by local bunching and debunching in a single proton bunch. So, this process is characterized by sufficient increasing of the transverse emittance and

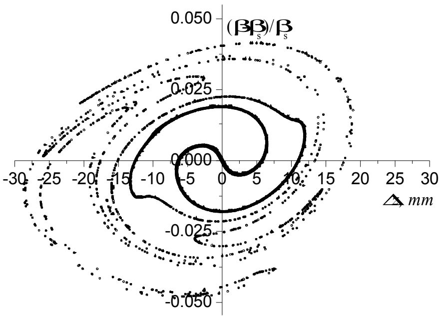

Fig. 2

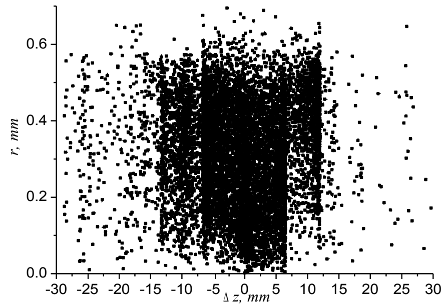

Fig. 2,a

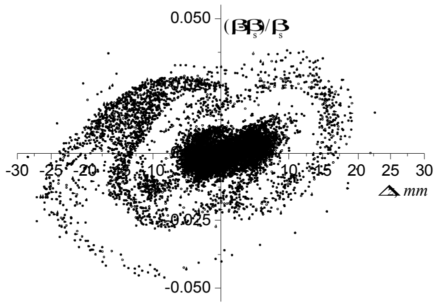

Fig. 3

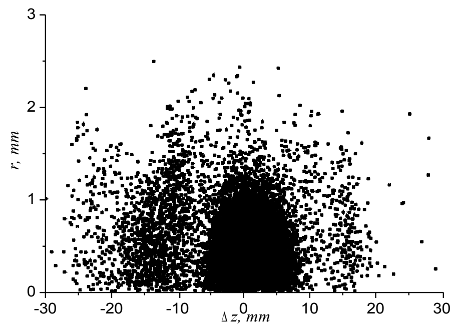

Fig. 3,a

decreasing of the longitudinal emittance at the accelerator output. For proton beam with current >150 mA the formation of the transverse emittance is finished up to 28-th accelerator period, i.e., the formation is realized

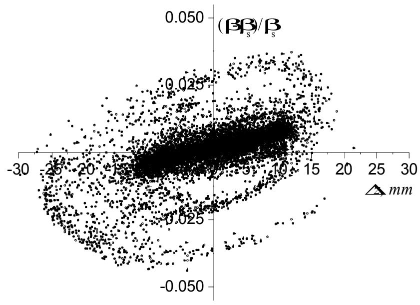

Fig. 4

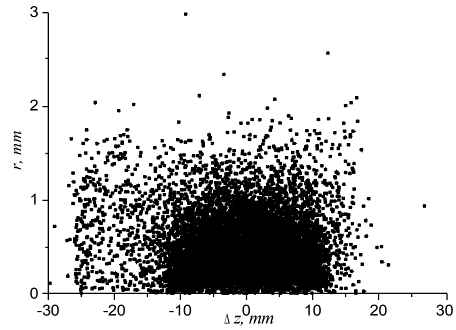

Fig. 4,a

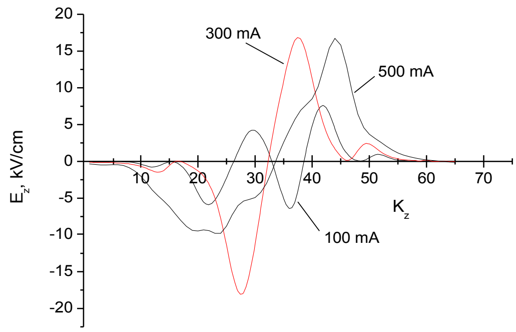

Fig. 5

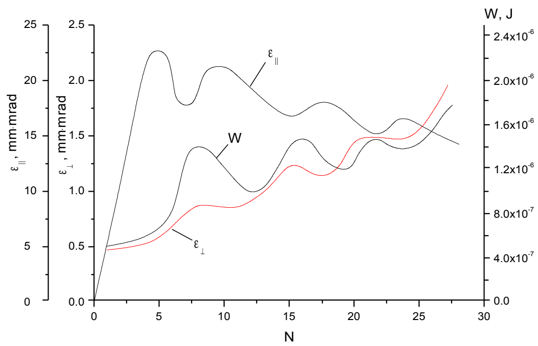

Fig. 6

on the initial part of the section with the length of 41 cm and proton energy increasing of 17.5 keV.

In Fig.6 it is presented the dependence of the transverse and longitudinal emittances upon the accelerator period number (for the proton beam current of 200 mA). Note, that the longitudinal emittance scale is decreased to 10 times. Also, in Fig.6 it is shown the change of the potential Coulomb energy of the proton bunch. In accordance with the phase focuses, the maximums of the transverse emittance coincide with the maximums of the potential Coulomb energy and minimums of the longitudinal emittance. After 30-th period the increase of the transverse emittance and the potential Coulomb energy stops. Further, to the accelerator end the transverse emittance decreases on 2.8%, the longitudinal emittance increases on 29%, the potential Coulomb energy decreases to 2 times.

The mechanism of the transverse emittance increasing can be observed from Figs.7,7,a. In Fig.7 it is shown the phase portrait of the 100 mA beam in the 7-th period that corresponds to first phase focus. For this case, in Fig.7,a one can see the proton density distribution in the (r,z) plane where the beam radius is strongly increased.

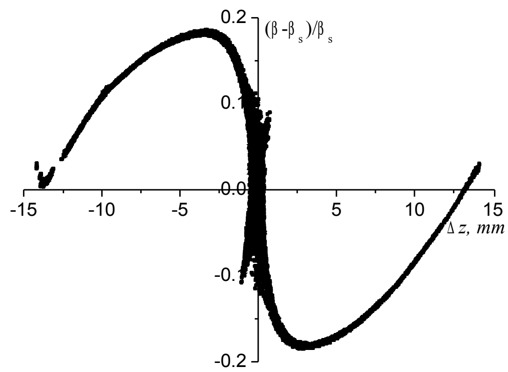

Fig. 7

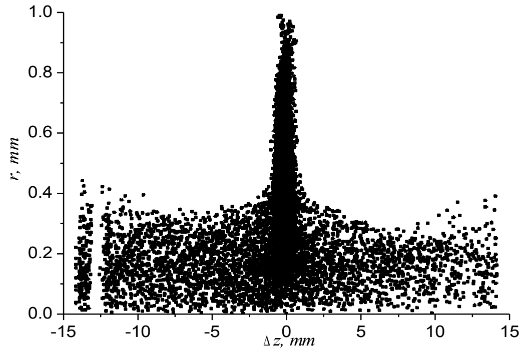

Fig. 7,a

4. CONCLUSIONS

The preliminary results of simulation show good prospects of electron beam focusing for development of high-current proton accelerators with current of 500–600 mA and more. For further developing of this direction it is necessary to develop a computer model that can account influence of different factors in more details. In part, it is need to join an electron gun, acceleration sections, proton beam injection into the accelerator, and recuperator of an intense electron beam in a single computer model.

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КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ НАЧАЛЬНОЙ ЧАСТИ ЛИНЕЙНОГО СИЛЬНОТОЧНОГО ПРОТОННОГО УСКОРИТЕЛЯ С ФОКУСИРОВКОЙ ЭЛЕКТРОННЫМ ПУЧКОМ

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Исследуется ускорение протонов с током 0.1…0.6 А, энергией до 3 МэВ. При этом параметры фокусирующего электронного пучка меняются в пределах: ток 40…100 А, энергия 100 кэВ, напряженность фокусирующего магнитного поля 2…3 кЭ. Коэффициент захвата протонов в ускорение достигает 99%.

КОМП'ЮТЕРНЕ МОДЕЛЮВАННЯ ПОЧАТКОВОЇ ЧАСТИНИ ЛІНЕЙНОГО СИЛЬНО-СТРУМОВОГО ПРОТОННОГО ПРИСКОРЮВАЧА ІЗ ФОКУСУВАННЯМ ЕЛЕКТРОННИМ ПУЧКОМ

Б.І. Іванов, М.Г. Шуліка

За допомогою комп'ютерного моделювання досліджується прискорення протонів із струмом 0.1…0.6 А, енергією до 3 МеВ. При цьому параметри фокусуючого електронного пучка змінюються у межах: струм 40…100 А, енергія 100 кеВ, напруженість фокусуючого магнітного поля 2…3 кЕ. Коефіцієнт захоплення протонів у прискорення досягає 99%.