BEAM DYNAMICS SIMULATION IN HIGH ENERGY ELECTRON COOLER

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Abstract

The article deals with electron beam dynamics in projected high energy electron cooler. Classical electrostatic scheme with several MeV electron energy is considered. The increase of transversal energy of electrons in an accelerating section, in bends and at the matching point of magnetic fields is calculated. In order to calculate beam behaviour in bends with electrostatic compensation of centripetal drift new ELEC3D electro- and magnitostatic 3D code is developed. BEAM code is used for simulation of dynamics in an accelerating section. The methods of keeping low transversal energy are estimated.

HESR ELECTRON COOLER

The subject of the article is the investigation of the electron beam dynamics in high energy electron cooler. Fast electron cooling of antiproton beams in the energy range between 0.8 and 14.5 GeV is a key feature for one of the major objectives of the GSI future plans: internal target experiments at the High Energy Storage Ring HESR [1]. The powerful cooling is required for the high resolution experiments investigating the structure of hadrons and the interaction of quarks and gluons in the nuclear medium.

The project of 8 MeV electron cooler proposed by BINP is based on classical electrostatic scheme. The electrostatic column is 8 m high; it consists of a number of sections with a potential growing from the bottom section to the top one. The insulating gas is SF_6 being under pressure to ensure the desirable electric strength. The electrostatic column has three accelerating tubes, two tubes for the acceleration and deceleration of an electron beam, and one for the charging of the column head. For the electrostatic cooler a small cyclotron for 10 MeV H^- ions as a charging system is proposed. Accelerated electron beam is bent in the vertical and horizontal planes and is moved to the cooling section. After the main solenoid the beam is returned to the electrostatic column, where it is decelerated to recuperate its energy. Longitudinal magnetic field accompanies electron beam along all its way.

ACCELERATING COLUMN

Accelerating part of proposed cooler is consisted from many accelerating sections. One meter long accelerating sections are planned to use, but in following calculations standard sections is used. The presence of gaps between accelerating electrodes in points of connection of neighbour sections leads to the strong pulsation of accelerating field (see Fig. 1). During its travel through accelerating column electrons are affected by radial oscillating force with constant space step aroused by these pulsations. Moreover, an electron has its own parameter – space step of larmour rotation. This step increases with the growth of electron energy. When these parameters are comparable resonant increase of transverse velocity may occur. Fig. 2 shows that following strikes can increase or suppress the transversal motion depending on magnetic field.

To minimize these undesirable pulsations it is proposed in the area, where step of larmour rotation is large enough, to hit beam by local change of magnetic field (see Fig. 3). Calculations show that this local field can be larger than mean value, or can be smaller. The second case is shown on the picture. To realize this no special

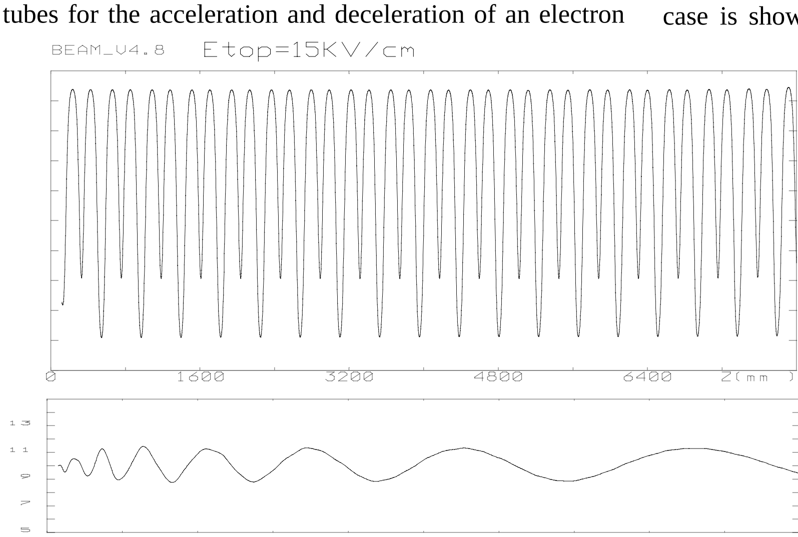

Figure 1: Axial distribution of electric field (top) and calculated beam envelope (bottom).

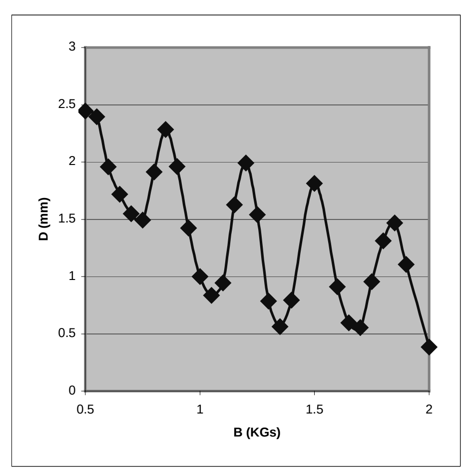

Figure 2: Diameter of the beam pulsations on the exit of accelerating column as a function of magnetic field.

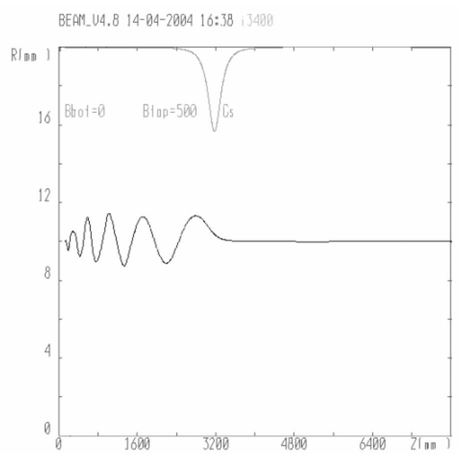

Figure 3: Minimization of beam pulsations.

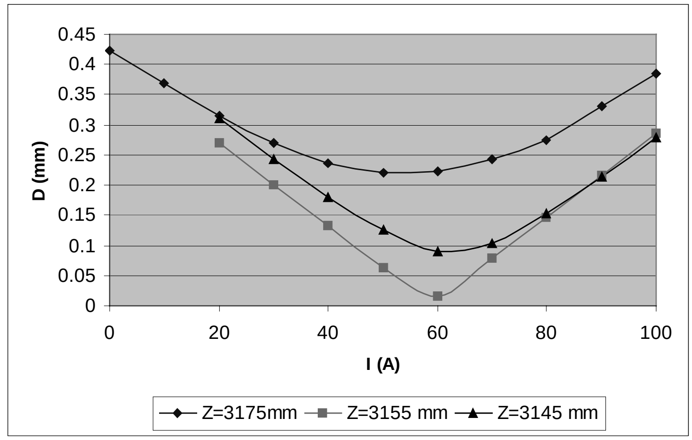

Figure 4: Dependence of diameter of beam pulsations from the position and current of test coil.

changes in magnetic system have to be done, just the current in one coil must be decreased. On Fig. 4 one can see how diameter of pulsations depends from the current and the position of this coil. With change of full energy the position and current of affecting coil must be changed; it is possible to use two or may be more coils to provide necessary effect.

BENDS WITH ELECTROSTATIC COMPENSATION

The motion of electrons in the cooler is not reversible as rule. It means that the electrons reflected from collector have a small chance to be absorbed in it after that. The magnetic field bending the electron beam in the toroid part of cooler affected in the opposite direction to the reflected electrons. So, these electrons fall to the vacuum chamber inducing outgassing process and becoming cause of the leakage current. The electrostatic compensation of centrifugal drift can help to achieve the reversible dynamic of electrons. The electrons reflected from collector can oscillate few times between a collector and a gun. During the time they can be absorbed ultimately in the collector. Thus, the leakage current can be strongly suppressed. This effect was observed experimentally on the EC-300 cooling device designed and manufactured at BINP for CSRe ring (IMP, Lanzhou). The observed collector efficiency was better than 10^{-6} [2].

To realize the electrostatic bending two plates forming the capacitor is placed in the toroid part. But this capacitor itself can excite transversal motion of electrons. The curvature of magnetic field force lines increases on the edges of toroids; and electric field has its own grows on the edges of the capacitor (see Fig. 5). If these two curves are different, beam oscillations are excited. To provide the necessary growth of electric field modification of edges of capacitor is proposed (see Fig. 6). Calculations show that this modification helps to minimize beam transversal energy. Beam pulsations in capacitor with non-modified and modified edges are shown on Fig. 7.

The electrostatic plate causes the problem with optics of electron beam in the domain of convergence of electron and antiproton beams. In this point some fraction of the bending plate is cut off by the aperture of antiproton beam. 5 KGs magnetic field in bends is proposed to use in order to minimize shifts of the electron beam in this region aroused by centrifugal drift. This field is strong enough for keeping of reflected electrons close to the orbit of the primary beam.

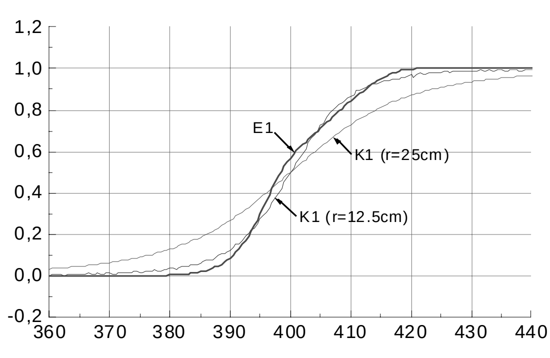

Figure 5: Matching of magnetic force line curvature with growth of electric field.

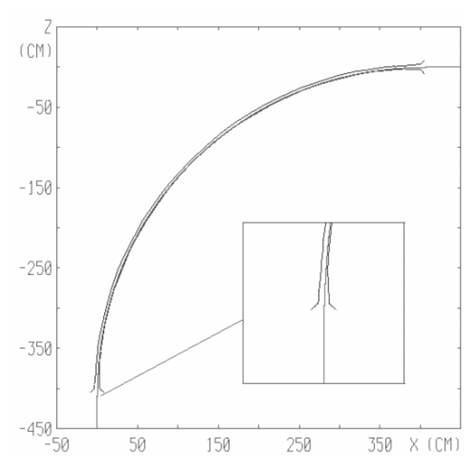

Figure 6: Modified edges of capacitor.

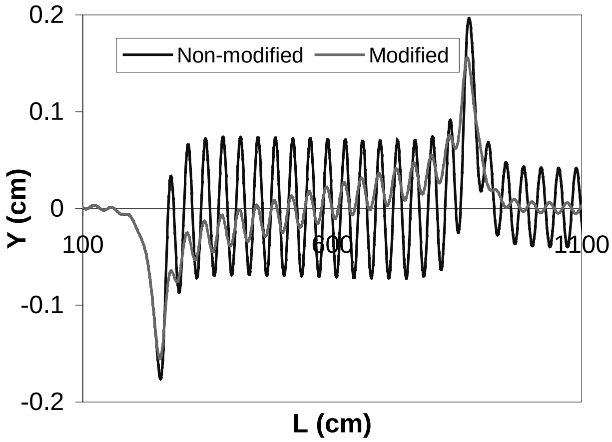

Figure 7: Beam pulsation in capacitor with non-modified and modified edges.

MATCHING POINT OF MAGNETIC FIELDS

In electrostatic column of projected HESR cooler value of accompanying magnetic field is chosen to 500 Gs. In bends and in cooling solenoid this field in ten times more, 5 KGs. So, special matching section must be included to provide transition of electron beam between these fields without excitation of transversal motion. With electron beam energy of 8 MeV, adiabatic entrance will be too long; shorter field growth leads to the strong beam pulsations (see Fig. 8, left). To make compact matching section another idea was proposed – the quarter-wave transformation section. Between low and high magnetic fields must be a region with field equal to:

$$B_{mid} = \sqrt{B_1 \cdot B_2}\ , \qquad (1)$$

length of this region must be equal to the quarter of space step of larmour rotation. In such magnetic field configuration strikes on the entrance into the section and on the exit compensate each other, and no transversal motion appears. Results of beam dynamics calculation in this section are show on Fig. 8, right.

CODES USED FOR CALCULATIONS

To calculate beam dynamics several codes developed in BINP are used. Beam behaviour in the accelerating column and in the matching point of magnetic fields is simulated by BEAM code [3]. This 2D code is developed for simulation of dynamics of non-laminar cylindrical beams with high perveance in long electron-optic systems. High order paraxial approximation is used for external electric and magnetic fields calculation. Axial distribution of external fields is calculated by SAM code. PIC method for space charge effects consideration is used. Beam start conditions can be imported from SAM and UltraSAM [4] codes.

To calculate beam dynamics in bends new ELEC3D code for 3D electrostatic calculations has been developed. ELEC3D code uses Boundary Elements Method. For this method open regions and extreme aspect ratios are not problems, and field solution is perfectly smooth. Special advantage of this method is that 3D mesh is not necessary, surfaces of elements only must be described. ELEC3D code is combined with MAG3D non-linear magnetostatic code to provide universal tool for 3D static calculations.

REFERENCES

[1] An International Accelerator Facility for Beams of Ions and Antiprotons. Conceptual Design Report. GSI, November 2001.

[2] V. Bocharov et al., “Commissioning of Electron Cooler EC-300”, EPAC 2004.

[3] M. Tiunov, “BEAM – 2D-code package for simulation of high perveance beam dynamics in long systems”, preprint BINP 98-78, 1998.

[4] A. Ivanov, M. Tiunov, “ULTRASAM - 2D Code for Simulation of Electron Guns with Ultra High Precision”, Proc. of EPAC 2002, p. 1634-1636.

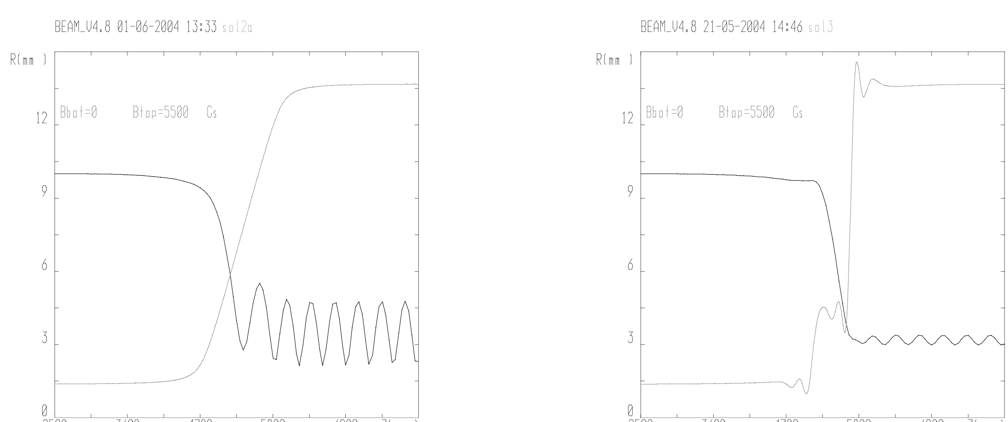

Figure 8: Entrance into strong magnetic field. Magnetic field and beam envelope are shown. Smooth growth of field (left) and quarter wave conversion (right).