SIMULATION OF THE BEAM DYNAMICS IN THE AXIAL INJECTION BEAM LINE OF FLNR JINR DC280 CYCLOTRON

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Abstract

DC280 is novel cyclotron which is created i the FLNR JINR. This cyclotron allows accelerating the ions of elements from Helium to Uranium with the mass to charge ratio in the range of 4 – 7.5 providing ion currents up to 10 pμA. The simulation of ion beam dynamics in the high voltage axial injection beam line of DC280 cyclotron is presented. One part of the injection system is placed at the High Voltage Platform and other part is in the grounded yoke of the DC-280 magnet. The 3D electromagnetic field maps of the focusing solenoids, analyzing magnet, accelerating tube and spherical electrostatic deflector are used during this simulation. The calculated efficiency of ion beam transportation is equal to 100%.

INTRODUCTION

The DC-280 [1] injection system has to provide ion beam transport from the ECR-ion source to the cyclotron centre and capturing into acceleration more than 70 % of ions with the mass to charge ratio of A/Z=4÷7.5 [2].

The experience of operation of FLNR cyclotrons demonstrates the substantial dependence of the efficiency of injection on the beam current for ions with energies of about 15 keV per unit charge. At the ion beam currents of 10 μA the efficiency of capture into acceleration reaches 50÷60 % while for the ion currents of 80÷150 μA it decreases down to 30÷35%. This effect may be explained by increasing of the beam emittance at high level of the microwave power in the ECR ion source and influence of the space charge on bunching of the ion beam. To improve the injection efficiency due to decreasing of both the emittance and the influence of space charge the injection energy has to be increased.

The axial injection system of the DC-280 cyclotron has two pieces of High Voltage Platforms (HVP). The maximal voltage on the HVP is 75 kV. Every HVP is equipped by an ECR ion source with injection voltage of 25 kV, the focusing elements (solenoids) and the magnets for ion separation. The high voltage accelerating tube is installed at the edge of the HVP to increase the ion energy (up to 100×Z keV in maximum). The acceleration in high voltage accelerating tube allows decreasing the ion beam emittance in about 1.5 times. The beam is matched at the entrance of the acceleration tube by means of the electrostatic lens.

For rotation of the ion beam onto vertical axis the spherical electrostatic deflector is used. To increase the efficiency of acceleration the multi-harmonic buncher is used. It is placed in the vertical part of the channel just after the electrostatic deflector. The buncher is working at 1, 2 and 3 harmonics of the RF system of the cyclotron. The ion beam emittance is matched with the acceptance of the spiral inflector by two solenoids installed at the vertical part of the beam line.

The numerical simulation of the ion beam dynamics in the axial injection channel has been performed by using the 3D electromagnetic field maps of the ECR ion source, solenoidal lenses, analyzing magnet [3], electrostatic lenses, accelerating tube and spherical electrostatic deflector [4]. All calculations have been done with the help of MCIB04 program code [5].

BEAM LINE ELEMENTS

Scheme of the axial injection channel is shown in Fig. 1

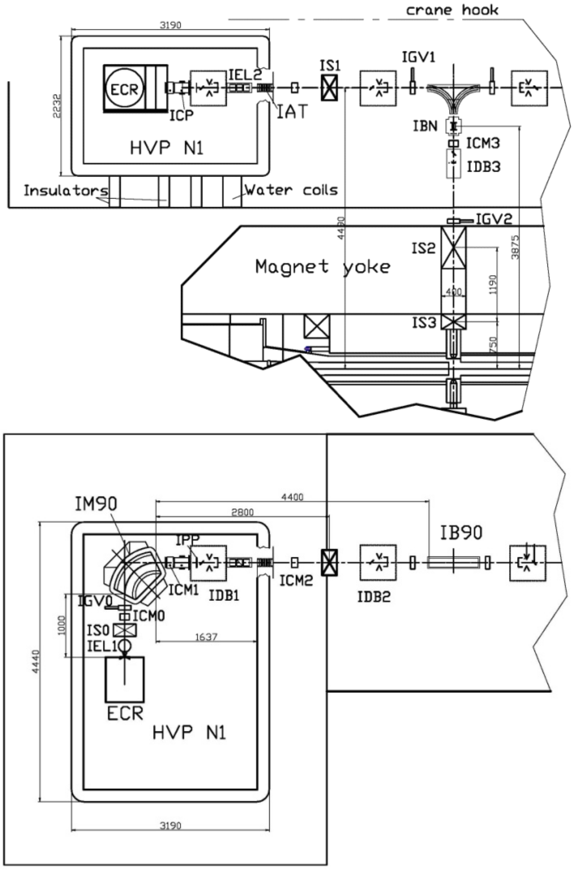

Figure 1: Scheme of axial injection channel. HVP – High Voltage Platform; ECR – ECR ion source; IS0-3 – solenoids; IM90 – analyzing magnet; IEL1,2 – electrostatic lenses; IAT – acceleration tube; IB90 – spherical electrostatic deflector; IBN – multi-harmonic buncher; IDB1-3 – diagnostic box.

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ISBN 978-3-95450-167-0

ECR Ion Source

Two types of ECR ion sources are installed at HVP: The permanent magnets ion source DECRIS-PM [6] and the superconducting ion source DECRIS-SC [7]. The first one has to produce high intensities (15÷20 pμA) of ions with medium masses (for example, $^{48}Ca^{7+,8+}$), the second one has to produce high charged heavy ions, such as $^{238}U^{39+,40+}$. The accelerating voltage U and magnetic field B on-axis distributions in DECRIS-PM ion source are shown in Figs. 2,3, correspondingly.

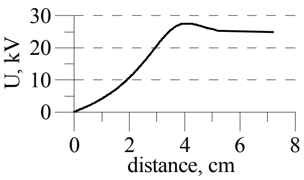

Figure 2: Accel. voltage

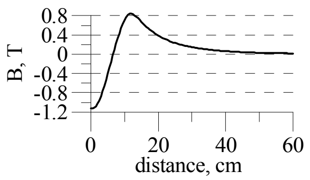

Figure 3: Magnetic field

Analyzing Magnet IM90

The 3D computational model of the magnet is shown in Fig. 4. The bending magnetic field distribution at reference orbit is shown in Fig. 5.

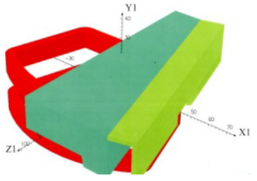

Figure 4: 3D magnet model.

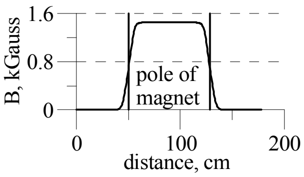

Figure 5: Bending field.

Lens IEL2 and Acceleration Tube IAT

The on-axis field strength E and voltage U of the lens IEL2 and the acceleration tube IAT are shown in Figs. 6,7.

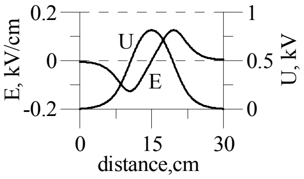

Figure 6: Lens IEL2.

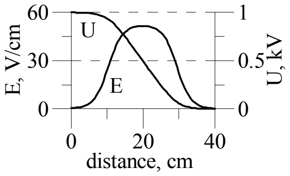

Figure 7: Accel. tube IAT.

Spherical Electrostatic Deflector IB90

The 3D model of the deflector is shown in Fig. 8. The bending electric field E is shown in Fig. 9.

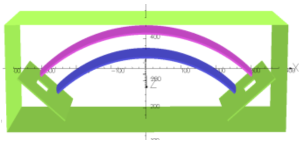

Figure 8: 3D deflector model.

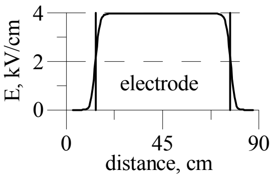

Figure 9: Bending electric field at reference orbit.

Focusing Solenoids IS0-3

The induction of the magnetic field B at the axis of the solenoids IS0-3 is shown in Figs. 10,11.

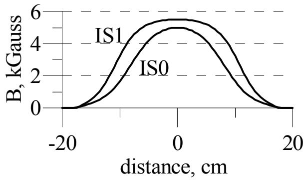

Figure 10: Solenoids IS0,1.

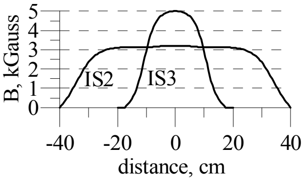

Figure 11: Solenoids IS2,3.

Multi-harmonic Buncher

In the presence of beam space charge the effect of bunching on transverse ion motion may be described by means of replacement of the beam current I by its effective value k_bI [8]. The dependence of bunching coefficient k_b on distance from the buncher is shown in Fig. 12.

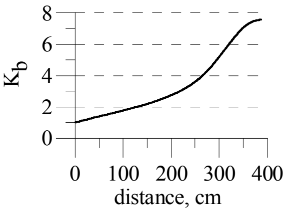

Figure 12: Bunching coefficient k_b.

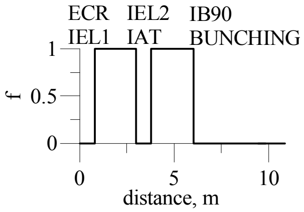

Figure 13: Neutralization factor f.

The efficiency of the beam bunching in the 20-degree phase interval of the accelerating RF field is equal to 80%.

BEAM NEUTRALIZATION

In the numerical simulations the full compensation of the beam space charge (by slow electrons accumulated in a beam) in all magnetic elements and drift spaces was supposed. The compensation was absent in the electrostatic elements, such as: the ECR ion source; the Einzel lenses IEL1,2; the deflector IB90; the accelerating tube IAT and also at the vertical part of the channel after the buncher IBN. The dependence of neutralization factor f on distance along the beam line is shown in Fig. 13.

CYCLOTRON MAGNETIC FIELD

The magnetic field of the cyclotron in the vertical part of the beam line B for various level of the magnetic field in the center B_0 is shown in Fig. 14.

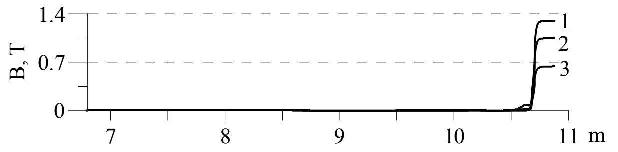

Figure 14: Cyclotron magnetic field. Curve 1 – B_0=1.3 T; curve 2 – B_0=1 T; curve 3 – B_0= 0.64 T.

SIMULATION REZULTS

The transport of $^{48}Ca^{8+}$ ion beam with kinetic energy of 75 keV×Z is presented as example. The calculated efficiency of the beam transport is equal to 100%. The dependence of the horizontal and vertical beam envelopes on length along the channel are shown in Fig. 15.

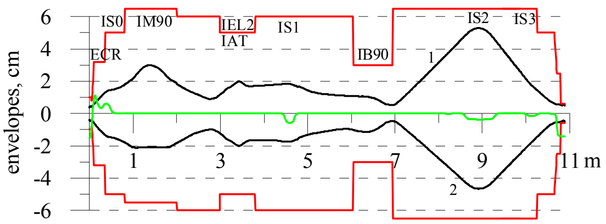

Figure 15: Horizontal (curve 1) and vertical (curve 2) $^{48}Ca^{8+}$ beam envelopes; aperture (red line) and longitudinal magnetic field (green line).

The beam envelopes near the magnetic plug and inflector are shown in Fig. 16. The designations are the same as in Fig. 15.

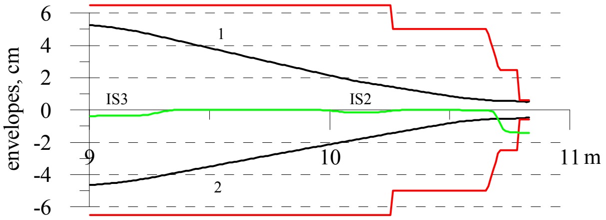

Figure 16: Beam envelopes near magnetic plug and inflector.

The kinetic energy W of the beam is shown in Fig. 17.

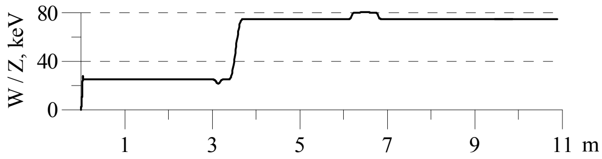

Figure 17: Kinetic energy per unit charge.

The horizontal (red curve) and vertical (blue curve) beam emittances are shown in Fig. 18. The decreasing of the beam emittance is explained by increasing of kinetic energy in the acceleration tube IAT.

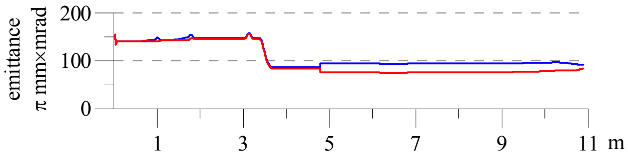

Figure 18: Beam emittances

The simulation results show that the system of the axial injection of the cyclotron complex DC-280 is able to provide the high efficiency of capture and subsequent acceleration of the beam up to the final energy.

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ISBN 978-3-95450-167-0