INJECTION AND ACCELERATION OF INTENSE HEAVY ION BEAMS IN JINR NEW CYCLOTRON DC280

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Abstract

At the present time the activities on creation of the new heavy-ion isochronous cyclotron DC280 are carried out at Joint Institute for Nuclear Research. The isochronous cyclotron DC-280 will produce accelerated beam of ions with A/Z= 4 - 7 to energy W= 4 – 8 MeV/n and intensity up to 10 pμA (for 48Ca). The goal for DC-280 accelerator complex is more then 40 % beam transfer efficiency. To achieve high-intensity ion beam, the cyclotron is equipped with high-voltage, up to 80 kV, injection line and independent Flat-Top RF system. To decrease the aperture losses at centre region the electrostatic quadruple lens will be installed between inflector and first accelerating gap. The paper presents the results of simulation of beam injection and acceleration.

INTRODUCTION

One of the basic scientific programs which are carried out in the FLNR JINR is synthesis of new elements which requires intensive beams of heavy ions. At present time the isochronous cyclotron U-400, which is in operation since 1978, is capable of providing long term experiments on 48Ca beams with an intensity of 1 pμA. Its operation time is more than 6000 hours per year. To enhance the efficiency of experiments it is necessary to obtain accelerated ion beams with the following parameters:

Ion energy 4÷8 MeV/n
Ion masses 10÷238
Beam intensity (up to A=50) 10 pμA
Beam emittance less 30 π mm mrad

These parameters formed the base for the new isochronous cyclotron DC-280 [1]. The basic technical solutions to realize new project are shown in Table 1.

Table 1: DC-280 Cyclotron - Basic Technical Solutions

Parameter DC280	Goals
1. High injecting beam energy (up to 100 keV/Z)	Decreasing space charge factor. Decreasing beam emittance.
2. High gap in the centre	Space for a long spiral inflector
3. Low magnetic field	Large starting radius. Good orbit separation. Low deflector voltage
4. High acceleration rate	Good orbit separation.
5. Flat-top system	High capture. Beam quality.

The new cyclotron complex provides an opportunity of carrying out physical and chemical research using radioactive targets, such as U, Pu, Am, Cm, Bk. The layout of the cyclotron assembling is shown in Figure 1.

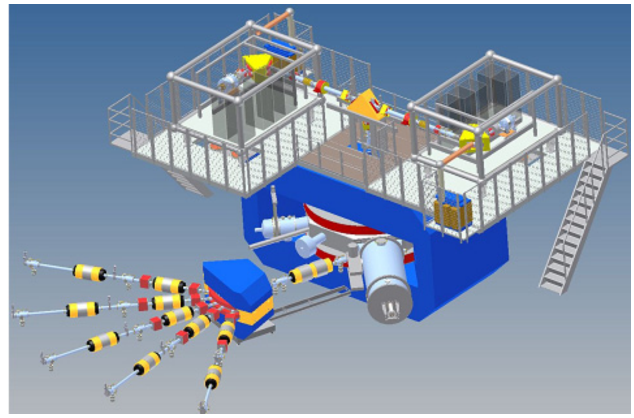

Figure 1: The layout of the DC-280 cyclotron.

Now the most of new cyclotron complex elements have been manufactured and the project is at the stage of laboratory building construction.

THE AXIAL INJECTION SYSTEM

The DC-280 injection system has to provide ion transition from the ECR-ion source to the cyclotron centre and capturing into acceleration more than 70 % of ions with the atomic mass to charge ratio of A/Z=4÷8 [2]. The experience in operation of FLNR cyclotrons demonstrates that at ion energies of 15 keV/Z the injection efficiency essentially depends on the ion beam current. At the ion beam currents of 80÷150 eμA the efficiency of capture into acceleration reaches 30÷35 %, but for the ion currents less than 10 eμA increasing of the efficiency to 50÷60 % has been observed. The reason of it may be the decreasing of the ion beam space charge effect and decreasing the beam emittance, especially at low level of the microwave power in the ECR source. To improve the injection efficiency we will increase the injection energy up to 100 keV/Z, since the emittance and the space charge effects have to be decreased.

The high-voltage axial injection of the DC-280 will consist of two high voltage platforms, HVP. The maximal voltage on the HVP will be 75 kV. Every HVP will be equipped with an ECR ion source with injection voltage 25 kV, a focusing elements and a magnet for ion separation and analyzing. The high voltage accelerating tube will be installed at the edge of the HVP to increase the ion energy.

Two types of ECR ion sources will be used: the DECRIS-PM source with permanent magnets and the DECRIS-SC superconducting one. The first ECR ion source has to produce high intensities (15÷20 pμA) of ions with medium masses (for example, $^{48}Ca^{7+,8+}$), the

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second one has to produce the high charged heavy ions, such as $^{238}U^{39+,40+}$.

The numerical calculations have shown that the acceleration in high voltage accelerating tube allows us to decrease the ion beam emittance in about 1.5 times. The calculated efficiency of the ion transport from the ECR to the DC-280 median plane is equal to 100 %.

To increase the accelerating efficiency the poly-harmonic buncher will be installed in the vertical part of the channel at the distance of 388 cm from the cyclotron median plane. The buncher uses 1, 2 and 3 harmonics of cyclotron RF voltage. The numerical simulation has shown that efficiency of beam grouping in range 20° of RF phase will be up to 80 %. The estimated beam losses at the grids are about 8-10 %.

DC280 MAGNET

To produce an isochronous field, DC280 magnet is equipped with four pairs of sectors. The aperture between the sectors is 208 mm and enough to place Flat-Top dees and 4 pairs of harmonic correcting coils, see Figure 2. The wide range of the magnetic field levels 0.64 – 1.32 T allows making a smooth variation of the beam energy in a range 4 – 8 Mev/nucl. For operational optimization of the magnetic field the 11 radial correcting coils are used. The beam phase divergence along acceleration not more than ±2° for 48Ca, Figure 3, and about ±15° for edge operation modes.

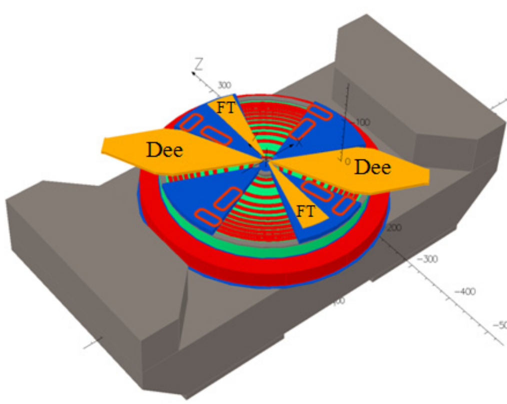

Figure 2: The model of DC-280 magnetic system.

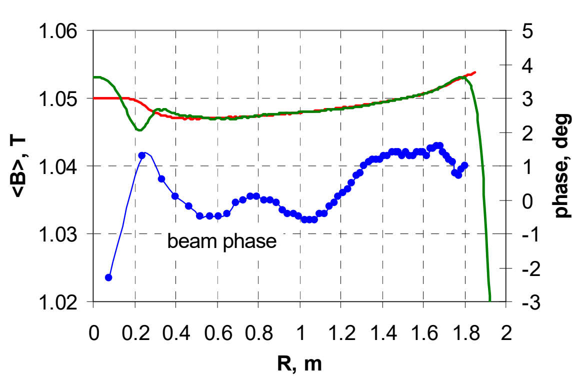

Figure 3: 48Ca8+ beam phase along acceleration, isochronous and formed magnetic field.

DC280 CENTRAL REGION

Because of a wide range of operation modes the DC-280 cyclotron uses electrostatic spiral inflector with different magnetic radiuses Rm = 7.5 and 9.2 cm. With the two interchangeable inflectors it is possible to maintain a high level of injection voltage in the range 50 to 85 kV. In this case a 100 % transmission of the injected beams through the axial injection system can be achieved.

The electric radii of both inflectors are the same and equal to Ae=6 см. To avoid the sparking between the electrodes the inflector voltage is not greater than ±16 kV. Inflector is placed at cyclotron centre by means of radial evacuating system. Because of two different starting radii the double puller of the first dee is used, Figure 4.

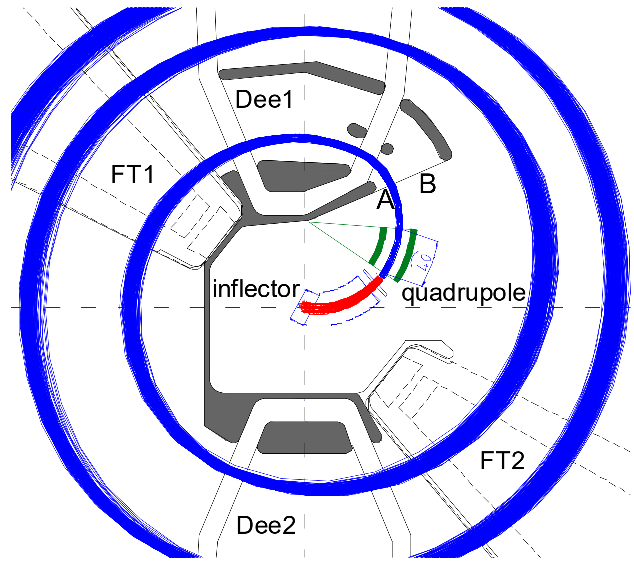

Figure 4: The central region of DC280 cyclotron. Inflector of 7.5 cm magnetic radius is placed.

The disadvantage of spiral inflector is vertical divergence of the beam at the exit. For DC280 it leads to about 25 % of aperture losses along the acceleration, especially at the first orbits. To avoid that losses an electrostatic quadrupole lens is placed between inflector and first accelerating gap, Figure 5.

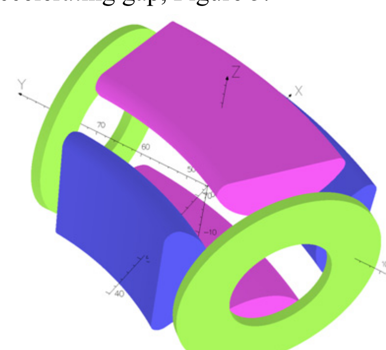

Figure 5: Quadrupole lens provides vertical focusing of the beam before first accelerating gap.

Quadrupole lens with aperture of 22 mm and length of 40 mm has a potential at electrodes 3 kV and provide

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vertical focusing of the injected beam before first accelerating gap. It decreases aperture losses along acceleration down to 2 %.

MAIN AND FLAT-TOP RF SYSTEMS

The cyclotron main accelerating system consist of two dees with 45° angular size and works at h_o=3 harmonic RF. The main resonator provides RF voltage in the range of 7.32-10.38 MHz and amplitude U_o up to 130 kV. The high voltage provides the high rate of acceleration and orbit separation, especially at the last orbits.

To achieve high-intensity ion beams, the cyclotron is equipped with Flat-Top system [3]. The scheme of two additional Flat-Top dees, worked at h_{ft}=3h_o=9 harmonic RF, was chosen. The Flat-Top dees are placed between the sectors in a gap of 208mm, at the angle 51.5° to the main dees and have angular size δ_{ft} = 20°. The Flat-Top RF voltage is 0.1 of the main dee voltage.

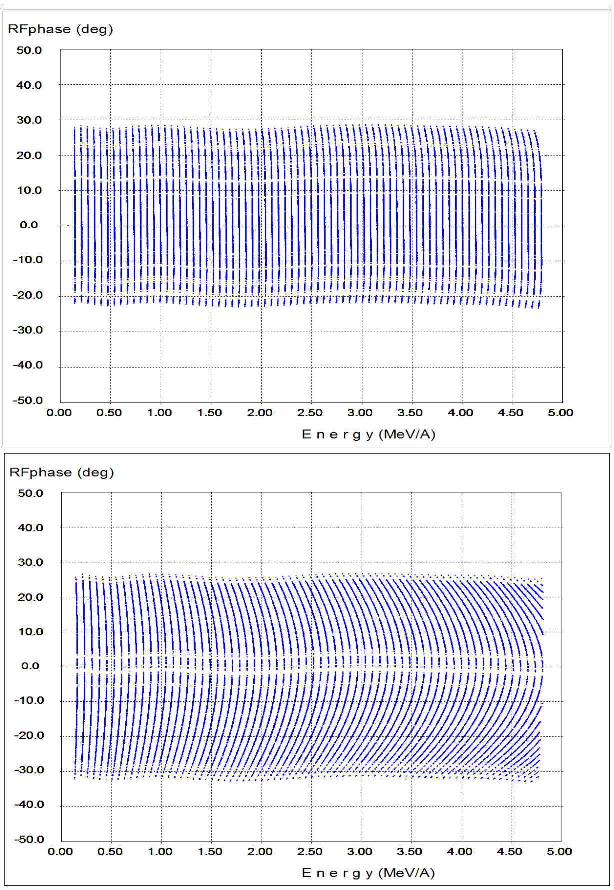

Figure 6. The energy – phase distribution of 48Ca beam along acceleration with and without Flat-Top system.

Figure 6 demonstrates the efficiency of Flat-Top system for 48Ca beam acceleration. The calculations have shown that the extracted beam has a good orbit separation before deflector and energy spread of about 0.5 %. The transition efficiency of acceleration from centre to deflector falls in a range 85 – 98 % and can be optimized by changing the phase and voltage of Flat-Top system.

BEAM EXTRACTION

The extraction system consists of electrostatic deflector and magnetic channel, Figure 7. Deflector is placed at radius 178 cm. Electric field 60 kV/cm deflect the beam and direct it to the benchmark of extracted beam line. The calculation has shown the losses at septum and inside deflector are about 8 % and 31 % respectively. For DC280 extraction system the total transmission factor is expected 60-70 %.

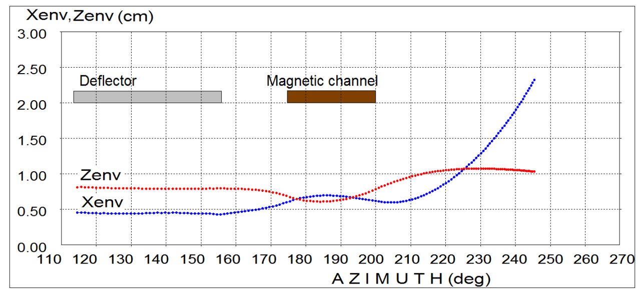

Figure 7: The 48Ca beam transverse dimension from last orbit to the benchmark of extracted beam line.

CONCLUSION

One of the main goals of SHE cyclotron complex DC-280 is an attainment of high intensity of 48Ca beam on a target. Table 2 presents our expectation of cyclotron transition factor range and a beam intensity from ECR, corresponded to 10 pmcA of 48Ca8+ on a target.

Table 2: DC-280 Cyclotron Transition Factor

	min	max
injection	70 %	80 %
acceleration	85 %	98 %
extraction	60 %	70 %
total	36 %	56 %
beam intensity from ECR	220 mcA	140 mcA

The results of calculations show that the designed parameters of DC280 cyclotron complex are achievable and can give a wide possibility to further upgrades.

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