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IMPROVEMENT OF THE BEAM TRANSMISSION IN THE CENTRAL REGION OF WARSAW U200P CYCLOTRON

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Abstract

To date, Warsaw U200P cyclotron exploited a mirror inflector to feed heavy ions extracted from ECR ion source (10 GHz, 11 kV) to the central region of the cyclotron. However, in such configuration very low transmission was reachable after many optimizations. Additionally, the new ECR ion source (14,5 GHz, 14-24 kV) was installed, which offers energies exceeding the energy acceptance of the currently operated inflector and central region. To avoid these obstacles, we have developed a spiral inflector and redesigned central region of the cyclotron. It was a very challenging task, bearing in mind limited volume of central region in our compact machine, to carve these elements suitably for decent versatility of ion beams offered by Warsaw cyclotron. This project was executed in the collaboration with FLNR in Dubna, Russia. The cyclotron equipped with the new central region works in the "constant orbit" regime. Here we present the results of both computational simulations and measurements of the beam transmission in upgraded central region.

COMPUTATIONAL SIMULATIONS

Introduction

The basic informations of U200P cyclotron are described in Refs. [1,2]. U200P cyclotron is an isochronous cyclotron (with four - sectors magnetic structure) equipped with two 45 degrees dees. The range of RF system's frequency is from 12 MHz to 18 MHz. The ions are accelerated using second and third harmonic with the range of the dee voltages from 50 kV to 70 kV. The scope of ions, which can be accelerated in U200P cyclotron is from A/q=4 to A/q=6,7, where A is a mass number and q is a charge state of the ion. The average magnetic field in the cyclotron amounts to 2T. The measured form of the magnetic field map used in all calculations and simulations is shown in Figure 1.

Spiral Inflector

A spiral inflector consists of two coaxial, spirally twisted electrodes, placed in the magnetic field.

According to the scope of the accelerated ions and the range of the injection voltage of the ECR ion source (14kV – 24kV), following parameters of the spiral inflector were chosen. To avoid the sparking effect the maximum potential on each electrode has to be not higher than 10kV. The height of the inflector is limited by the existing geometry in the central region of the cyclotron and equal to 40mm. The electric radius, which corresponds to the energies of the ions produced in the ion source, amounts to 25mm. Taking into account the electric radius and the maximum voltage on the electrode, the aperture of the inflector has to be equal 10mm. The width of the electrodes amounts to 20mm, due to the fact, that the ratio between the width and the spacing of the electrodes should be equal 2 to minimise the fringe field effect. According to all above mentioned parameters, the appropriate magnetic radius of the designed spiral inflector should amount to 2,16 cm. The main influence on the trajectory of the ions inside the spiral inflector and at the first accelerating gap has a minimum and the maximum injection voltage (14kV and 24kV) and the adequate level of the magnetic field in the cyclotron centre.

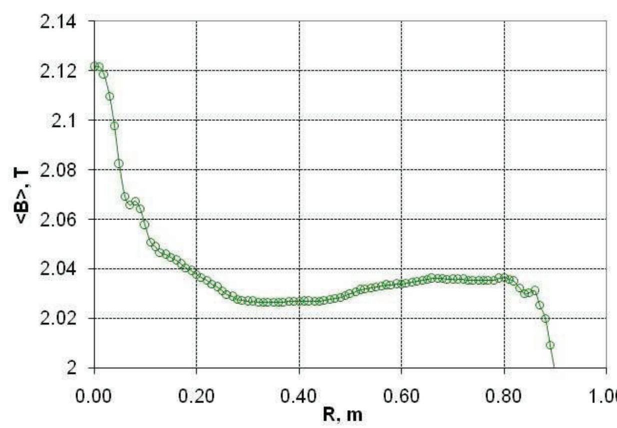

Figure 1: Magnetic field map of U200P cyclotron.

Calculations

All calculations were done for two extreme regimes for U200P cyclotron, which means the minimum and the maximum injection voltages and A/q ratio. These two cases are listed below:

- $^{16}O^{4+}$; U_{inj} = 23,3kV; U_{dee} = 65kV; B_0 = 2,037T; 2h; f = 15,33MHz
- $^{20}Ne^{3+}$; U_{inj} = 14kV; U_{dee} = 65kV; B_0 = 2,037T; 3h; f = 14MHz.

The spiral inflector and the new central region is designed to work in the "constant orbit" regime. Each ion has the same trajectory in the spiral inflector and before the first acceleration gap, which is secure by varying the injection voltage of the ion source and the potential at the inflector's electrodes. For both calculation regimes the transverse emittance at the entrance of the spiral inflector was defined as 150 π mm mrad.

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In order to design the spiral inflector and the new central region different code were used. Two of them are well known codes developed by TRIUMF in Vancouver (Relax 3D and Casino). Remaining code is developed by JINR in Dubna. They are listed below:

- Relax 3D [3] – electrostatic field calculations,
- Casino [4] – trajectory of the ions inside the inflector,
- Centre [5] - trajectory of the ions after the inflector.

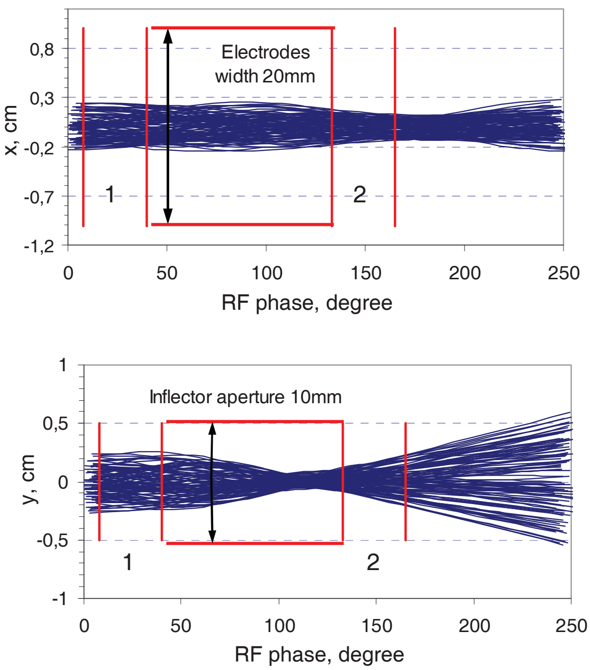

Figure 2: Trajectory of $^{16}O^{4+}$ inside the spiral inflector.

The calculated trajectory of $^{16}O^{4+}$ beam inside the spiral inflector is shown in Figure 2. The beam in the horizontal direction is focused and well defined inside and at the exit of the inflector. The defocusing at the exit of the inflector can be observed in the vertical plane. At an early date such inconvenience will be eliminated by using special shape of the electrodes [6] or adding some focusing system before the first accelerating gap.

The trajectory of $^{16}O^{4+}$ beam through the first accelerating gap and at the first few orbits is shown in Figure 3. On this drawing the hitherto used central region geometry, but with the spiral inflector instead of mirror one is shown. On the basis of these simulations the new compact central region without additional pillars and the appropriate pullers (noses of the dees) were designed.

MEASUREMENTS

The electrodes of the spiral inflector and the view of the central region with new elements are shown in Figure 4 and Figure 5 respectively.

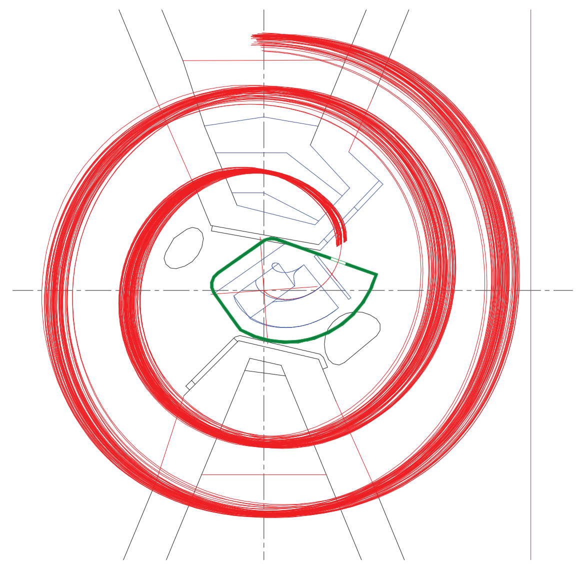

Figure 3: Trajectory of $O^{16\,4+}$ through the first accelerating gap.

Since installation in February 2014 few experiments with new system were done. All beams, which were produced up to this time in the new ECR ion source, where successful injected to the cyclotron and accelerated to the extraction orbit (82cm). Few examples of the accelerated beams with received currents after few turns (first legible position of the probe - 12,5 cm) are listed below:

- $^{4}He^{1+}$ - 24μA (300μA before the inflector's entrance)
- $^{20}Ne^{3+}$ - 18,8μA (160μA before the inflector's entrance)
- $^{12}C^{3+}$ - 18μA (100μA before the inflector's entrance)

Figure 4: The electrodes of the spiral inflector.

CONCLUSION

After taking into account all the physical constraints imposed by the ion source and the existing structure of

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the cyclotron, the spiral inflector and the new central region for U200P was designed and installed. First experiments show, that all elements work correct. The efficiency of the transmission at the first few orbits could be increased through the elimination of the defocusing of the beam in the vertical plane at the exit of the inflector.

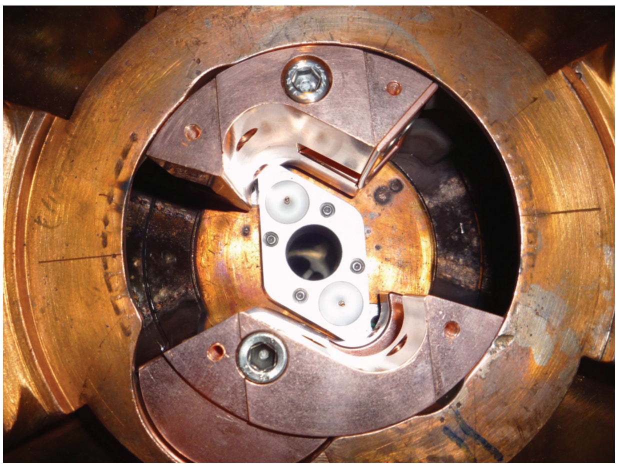

Figure 5: New central region of U200P cyclotron.

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