DESIGN OF THE CENTRAL REGION OF THE NEW MULTI-PURPOSE CYCLOTRON U400R

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Abstract

At the present time, the activities on creation of the new multi-purpose isochronous cyclotron U400R are carried out at the FLNR, JINR. The isochronous cyclotron U400R is intended for obtaining the beams of the accelerated ions from $4He^{1+}$ (A/Z=4, W=27MeV/u) up to $132Xe^{11+}$ (A/Z=12, W=3.5MeV/u). The cyclotron magnetic field can be changed from 0.8T to 1.8T and allow the smoothly variation of the ion beam energy at the range ±35% from nominal. The cyclotron RF system keeps up 2 ÷ 6 harmonic modes. The aim of the present work is to investigate the optimal geometry of U400R cyclotron center for the wide range of acceleration regimes. The computation of the beam acceleration is carried out by means of the computer code CENTR.

INTRODUCTION

The U400R cyclotron is an isochronous cyclotron with azimuthally varying field. It is designed as multipurpose machine and has to be able to accelerate wide range of the ion beams $^{4}He^{1+}$ ÷ $^{132}Xe^{11+}$ (mass to charge ratio range 4 ÷ 12) up to the energy W= 27 MeV/u ÷ 3.5 MeV/u. The expected intensity of the beams has to be increased more then two times in comparison with U400 cyclotron. The cyclotron working diagram is presented in Fig. 1.

The cyclotron is equipped with an ECR ion source. The ions are extracted from the source, transported along the axial transport line and bent onto median plane by the spiral inflector. The magnet structure has the axial centre plugs and four pairs of 45° sectors. There are two 40° dees located at the opposite "valleys". The RF generator frequency range 6.5 ÷ 12.5 MHz gives the five modes of cyclotron operation, from 2nd to 6th RF harmonics. The main parameters of magnet and RF system at the central region are presented at the Table 1.

The wide range of ions, A/Z = 4 ÷ 12, and magnetic field variation, 0.8T ÷ 1.8T, necessitate using more then one spiral inflector and a wide range of the RF harmonics. Moreover, the efficiency of the beams acceptance onto acceleration at the different RF harmonic modes required the different angular positions of the first acceleration gaps. In this case it is more convenient to separate U400R cyclotron working regimes in three groups with different spiral inflectors and RF harmonic modes:

"A" – 2 and 3 RF harmonic modes,

"B" – 3 RF harmonic mode,

"C" – 4, 5 and 6 RF harmonic modes.

The construction of the central region has to be stationary and not separable for accelerating at the different RF harmonic modes. To do this the beams of "A" and "B" working regime groups are accepted onto acceleration at the 1st dee puller, and the beams of the "C" group – at the opposite, 2nd dee puller.

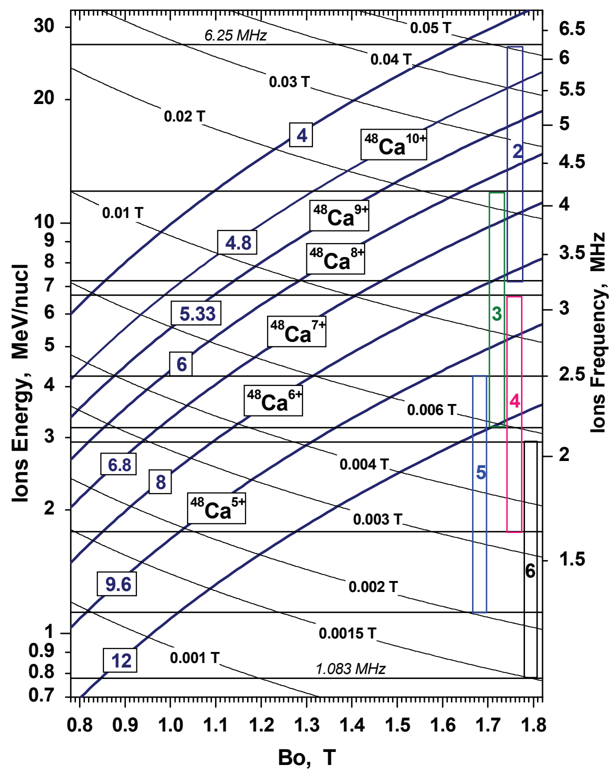

Figure 1: The working diagram of the U400R cyclotron.

Table 1: U400R Cyclotron Centre Main Parameters

Distance between centre plugs	82 mm
Centre plug radius (sectors inner radius)	100 mm
"Valley" ("hill") gap	300(56) mm
Dee aperture at the centre and next	20(30) mm
Maximal dees voltage	80 kV
RF harmonic modes	2, 3, 4, 5, 6
Magnetic field operation range	0.8T÷1.8T
Extraction voltage of ion sources	≤ 22kV
Minimum width of acceleration gap	10 mm

According to the working diagram the ranges of RF harmonic modes intersect. So the same ion beam can be accelerated at different harmonic modes. The optimisation of the cyclotron centre region is carried out with CASINO, CENTR [1, 2, 3] and Relax3D computer codes. For beams dynamics calculation the 3D calculated magnetic field maps are used.

SPIRAL INFLECTORS

The limitation of the voltage of the axial injection and the wide range of the main magnetic field level leads to using three spiral inflectors with different magnetic radii R_m. These inflectors are used at the operation modes "A", "B" and "C". The main parameters of the inflectors are presented in Table 2.

Table 2: Spiral Inflectors for U400R Cyclotron

Mode	RF harmonic	R_m	A_e	Aperture	k'
A	2, 3	30 mm	35 mm	12 mm	0
B	3	39 mm	35 mm	12 mm	0
C	4, 5, 6	47 mm	35 mm	12 mm	0

The distance between the centre plugs and the possible dimension for the inflector box define the inflector geometric parameters, the inflector height A_e and aperture. The "A" and "B" mode inflectors transmit the beams at the 1st dee direction, Fig. 2. The "C" mode inflector transmits the beams at the 2nd dee direction, Fig. 6. To change the cyclotron operation mode the inflector exchange system is used. This system moves the inflector radially through the sluice at the side of the cyclotron vacuum camber. The inflector exchange system provides the operative adjustment of the inflector position by rotation around z-axis at the angle ±8° and moving along R-direction ±2 mm. The inflectors are shielded from RF at the central region by stationary placed ground box.

CENTRE REGION

The centre region of U400R cyclotron has to be optimized for the operating modes with the different RF harmonics modes from 2nd up to 6th. For design purpose the typical ion beams for different RF harmonics modes were chosen. At the calculations the aperture of the both dee pullers 20 mm and width of acceleration gaps 10mm were taken.

Table 3: The Typical Ion Beams

	A/Z	Bo [T]	RF harmonic	U_{inj} [kV]	R_{start} [mm]
$^{4}He^{1+}$	4	1.8	2	24	51
$^{48}Ca^{7+}$	6.86	1.5	3	24	62
$^{48}Ca^{5+}$	9.6	1.3	5	19	82

"A" and "B" modes, 2 and 3 RF harmonics

The "A" and "B" operation modes are intended to inject and accelerate the ion beams at 2 and 3 RF harmonics. The first accelerating gap for these modes is placed at the 1st dee, Fig. 2. From the calculations it was found that the optimal angle of the first gap position for both modes is 35° from the dee axes. The modes have different starting radii at the first accelerating gap.

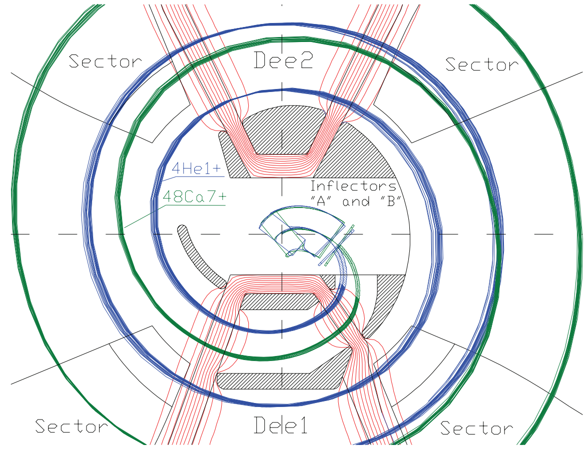

Figure 2: The first orbits of $^{4}He^{1+}$ and $^{48}Ca^{7+}$ ion beams at 2 and 3 RF harmonics respectively. In the figure "A" and "B" operation modes are combined.

For "A" operation mode the optimal starting radius is R_{str}=51mm, for "B" operation mode - R_{str}=62 mm. The test $^{4}He^{1+}$ ion beam, "A" operation mode, has a minimal increment of the radius and limits the centre dimension. In Figs. 3 and 4 the $^{4}He^{1+}$ ion beam emittance and the cyclotron radial and vertical acceptances for different initial phases are presented. The radial acceptance presents limitations of no more than 5 mm in centering the first one of the 5 beam orbits. In Fig. 3 the line of central particle position presents the possible displacement of radial emittance while inflector is rotated around z-axis. The changing of dee voltage up to 80 kV allows to tune radial acceptance position on RR' plane.

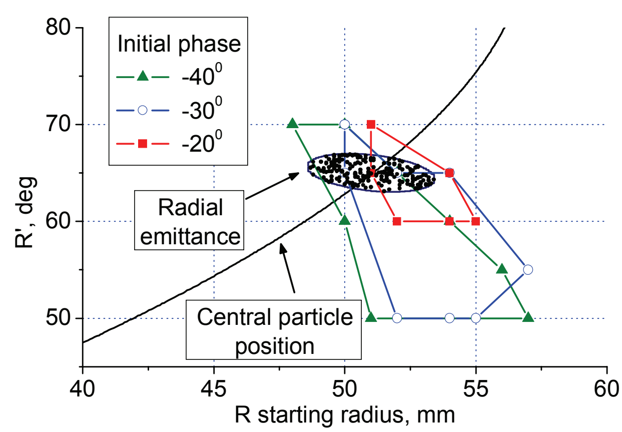

Figure 3: "A" operation mode. The cyclotron radial acceptance and $^{4}He^{1+}$ ions beam emittance.

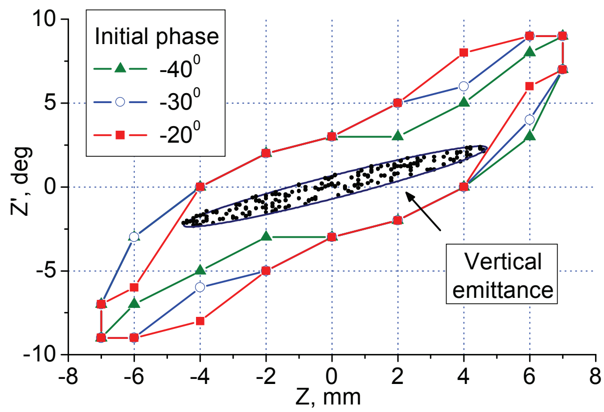

Figure 4: “A” operation mode. The cyclotron vertical acceptance and $^{4}He^{1+}$ ions beam emittance.

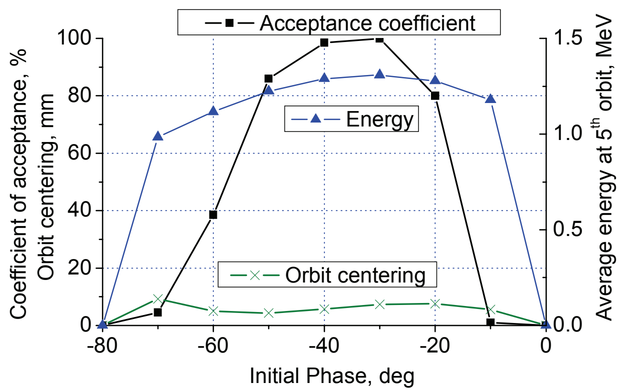

Figure 5: The efficiency, orbit centring and average energy of $^{4}He^{1+}$ ion beam at the central region.

The efficiency of $^{4}He^{1+}$ ion beam acceleration at the central region, for first five orbits, is presented in Fig. 5. The phase range of the effective acceptance into acceleration is about 50°. The calculation of test $^{48}Ca^{7+}$ ion beam of “B” operation mode has the similar results.

“C” mode, 4, 5 and 6 RF harmonics

The “C” operation mode combines the acceleration at 4, 5 and 6 RF harmonics and uses one spiral inflector with magnetic radius R_m=47 mm. A compromise angle position of the first accelerating gap is 25° from the dee axes was found. The beams of the “C” operation mode start into acceleration at the radius about 82 mm, Fig. 7. The “C” operation mode radial acceptance in Fig. 7 presents limitations of no more than 10 mm in centering the first one of the 5 beam orbits.

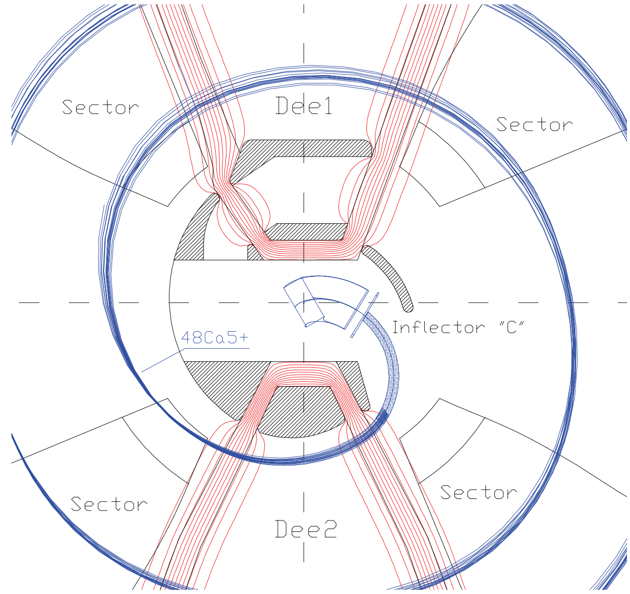

Figure 6: The first orbits trajectories of $^{48}Ca^{5+}$ ion beam at 5 RF harmonics, “C” operation mode.

The trajectories of ion beams, accelerated from 1st dee, prevent to place pillars to form first accelerating gap of the 2nd dee. That leads to RF field penetration inside the dummy-dee, and to increasing the gap effective length. As a result the acceptance efficiency a highest, 5 and 6 RF harmonics is decreased. The optimal angle positions of the first gap and the special form of the inflector box allow to minimize the action of RF deceleration phase on the sides of accelerating gap, Fig. 8, and provide the cyclotron acceptance with high efficiency.

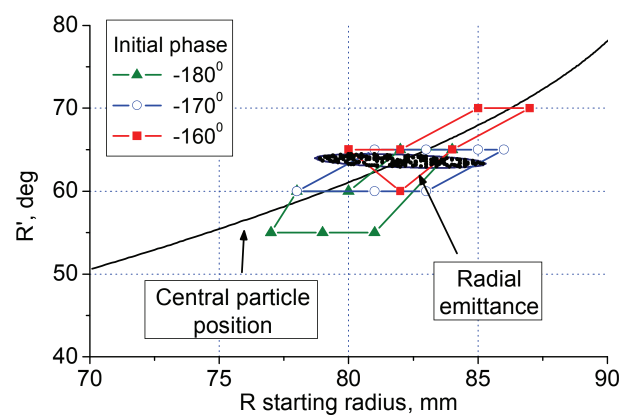

Figure 7: “C” operation mode. Radial acceptance and optimal position of the $^{48}Ca^{5+}$ ion beam emittance.

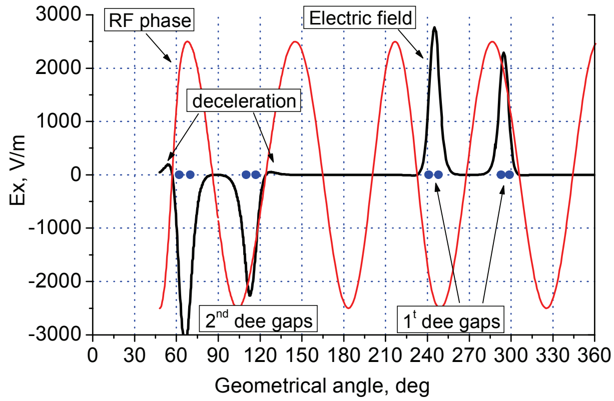

Figure 8: The RF phase and azimuth component of electric field acted on $^{48}Ca^{5+}$ central ion.

CONCLUSION

The design of the centre region of U400R multi-purpose cyclotron is curried out. The cyclotron operating modes are separates in three groups with different spiral inflectors and RF harmonic modes. The concept of acceleration from the both 1st and 2nd dees let us to optimize the angular position of the first accelerating gap for 2 and 3 harmonic modes and for 4, 5 and 6 harmonic modes separately and use the stationary placed central region geometry. To change the cyclotron operation modes one needs only to exchange the spiral inflector.

REFERENCES

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