BEAM INJECTION AND FIRST ORBITS AT 2 TO 6 RF HARMONIC MODES AT THE CENTRAL REGION OF DC-72 CYCLOTRON.

G. Gulbekian, I. Ivanenko, FLNR JINR, Dubna, 141980 Russia

Abstract

The DC-72 cyclotron is designed to accelerate ions with A/Z from 1 (H-) to 7.167 (129Xe+18) up to a final energy of 72 MeV/n and 2.7MeV/n, respectively. To cover all cyclotron working regimes, the RF system keeps up 2 ÷ 6 harmonic modes. The optimal design of cyclotron center for acceleration of the ion beams at 2 to 6 RF harmonic modes is investigated. The computation of the beams acceleration is carried out by means of the computer code CENTR.

INTRODUCTION

The DC-72 Cyclotron is an isochronous cyclotron with azimuthally varying field. It is designed as a multipurpose machine. It should be able to accelerate various ion beams into a wide energy range, from H- (72Mev/u) up to 129Xe+18 (3.2MeV/u). The working diagram of the DC-72 cyclotron is presented at the figure 1.

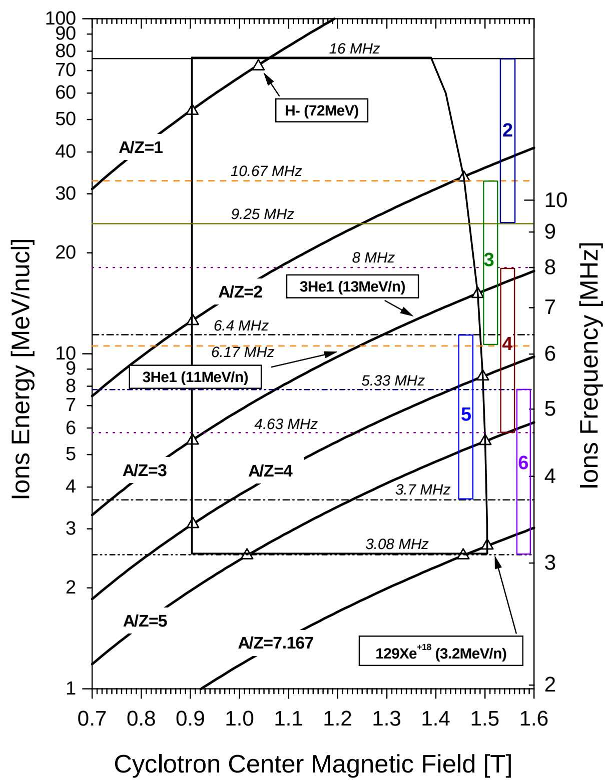

Figure 1: The working diagram of the DC-72 cyclotron.

The cyclotron is equipped with ECR and multicasp ion sources. The ions are extracted from the source, transported with the axial transport line and bent onto median plate by the spiral inflector. The magnet structure has the axial centre plugs and four pairs of 45° sectors. There are two 40° dees are located at the opposite "valleys". The main parameters of magnet and RF system at the central region are presented at the table 1. Five modes of cyclotron operation (2nd to 6th harmonic numbers) are necessary to cover the entire operating range. The phase conditions for optimal acceleration of the beams at the different harmonic number modes are different. It is especially important for the beam accepting at the central region. The more effective way is to separate working regimes by a three groups with the different harmonic numbers. At the case of DC-72 cyclotron three modes are chosen: "A" – 2 and 3 harmonics, "B" – 4 harmonic and "C" – 5 and 6 harmonics. To combine all these modes at the central region the beam accepting onto acceleration for 2 and 3 harmonics take place at the 1t dee, for 4, 5 and 6 harmonics – at the opposite, 2nd dee.

Table 1: The cyclotron centre main parameters

Distance between centre plugs	88 mm
Centre plug radius (sectors start radius)	70 mm
"Valley" ("hill") gap	280(90) mm
Dee aperture at the centre and next	20(30) mm
Maximal dees voltage	60kV
Magnetic field operation range	0.9T÷1.53T
Extraction voltage of ion sources	≤ 22kV
Minimum width of acceleration gap	10mm

The ranges of harmonic modes intersect. So the same ion beams can be accelerated at the different harmonic modes. The optimisation of the cyclotron centre region elements is curried out with CASINO, CENTR [1,2,3] and Relax3D computer codes. For beams dynamic calculation the measured magnetic field dates are used.

SPIRAL INFLECTORS

The three spiral inflectors for each operation mode, "A", "B" and "C" are used. The distance between the centre plugs and the possible dimension for the inflector box defines inflectors geometric parameters. The main parameters of those inflectors are presented at the table 2.

Table 2: Spiral inflectors for DC-72 cyclotron

Mode	Harmonic	Rm	Ae	do	k'
A	2, 3	18mm	18mm	10mm	0
B	4	24.7mm	20mm	10mm	0
C	5, 6	28.7mm	20mm	10mm	0

The “A” mode inflector transmits the beams at the 1^{t} dee direction. The “B” and “C” modes inflectors transmit the beams at the 2^{nd} dee direction. To change the cyclotron operation mode the inflector exchange system is used. It is located in the upper axial channel. At the same time this system provide the operative adjustment of the inflector position by rotation around z-axis ($\pm 8^{o}$) and translation along z-axis ($\pm$2mm). The inflectors are shielded from RF at the central region by the stationary placed ground box.

CENTRAL REGION

At the first accelerating gaps the ions receive the energy comparable with their initial energy at the axial injection system. The width and angle position of the first accelerating gaps is the very important parameters and define the efficiency of acceleration. At the case of DC-72 cyclotron the centre region geometry must be optimal from 2^{nd} up to 6^{th} harmonics modes. Moreover, this geometry must ensure the cyclotron operation without sparking. The cyclotron RF system operates with maximal voltage 60kV and minimal frequency 18MHz. For those parameters the Kilpatrick sparking criterion gives 64kV/cm. The minimum width of acceleration gaps is 10mm. Some working regimes were chosen for design purposes. At the table 3 the general parameters for typical ion beams are presented.

Table 3: The typical ion beams.

A/Z	Bo [T]	RF harmonic	U_{inj} [kV]	R_{start} [mm]
1	1.031	2	16.58	32.6
3	1.38	3	9.92	33
3	1.275	4	15.95	40
7.167	1.53	6	13	52

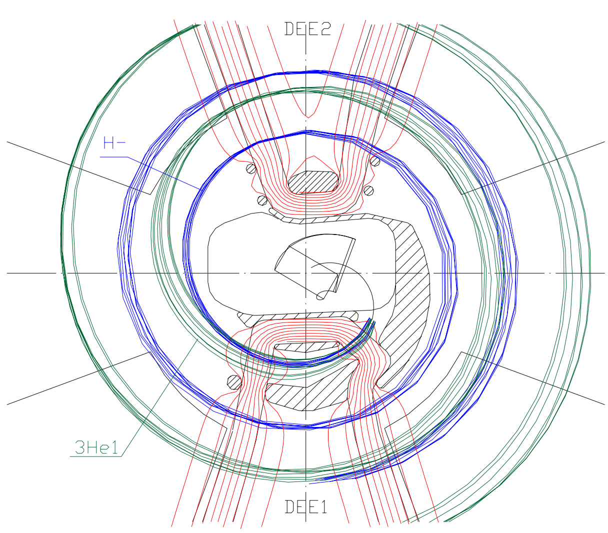

Figure 2: The first and second orbits of H- and 3He1 ion beams at 2 and 3 RF harmonics respectively.

2 and 3 RF harmonic modes

The “A” operation mode is intended to inject and accelerate the ion beams at 2 and 3 RF harmonics. The first accelerating gap is placed at the 1^{t} dee, figure 2. The optimal angle of the gap position is 37^{o} from the dee axes. At the figure 3 the matching of H- ions beam emittance into the cyclotron acceptance for different initial phases is presented. The line of central particle position presents the possible displacement of radial emittance with the inflector rotation around z-axis. At the figure 4 the acceptance efficiency, orbit centring and average energy for the 5^{th} orbit of H- ions beam, 200 particles inside the emittance at the figure 3, are presented.

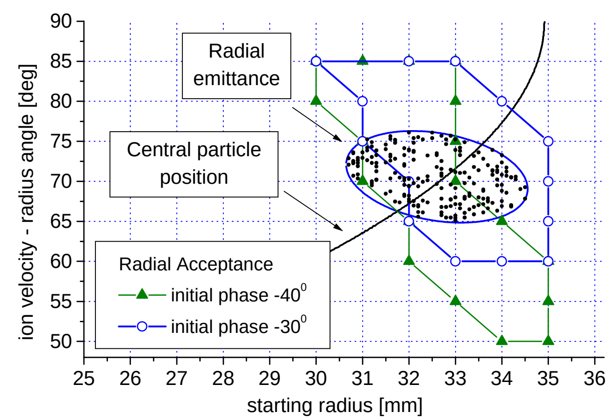

Figure 3: Radial acceptance for initial phase –30^{o} and optimal position of the H- ions beam emittance.

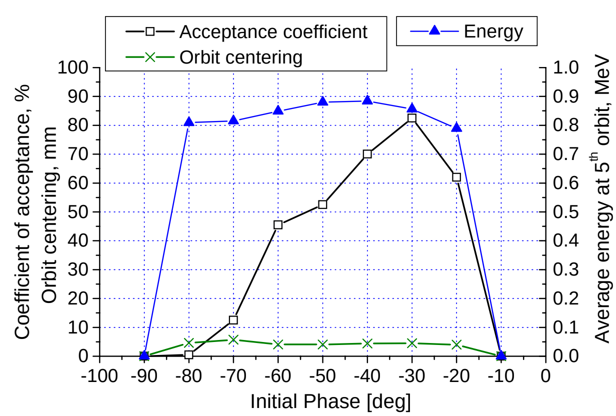

Figure 4: The efficiency, orbit centring and average energy of H- ion beam, considered at figure 3.

4, 5 and 6 RF harmonic mode

The purpose of separation of the “B” and “C” operation modes is increasing of the acceptance coefficient, on the one hand. On the other hand, the operation modes need to use more than one inflector. This requirement is defined by limitation of extraction voltage of ion sources, $V_{ext} \leq 22$kV. Taking into account the initial conditions from table 1, two inflectors with R_m=24.7mm and 28.7mm are chosen for the “B” and “C” operation modes respectively. For 4 harmonic the acceleration starting radius for the beams of “B” mode is about 40mm, figure 5. The beams of the “C” mode start into acceleration at the higher radius, about 52mm, figure 6. At the both cases the first gap positions are 20° from the dee axes.

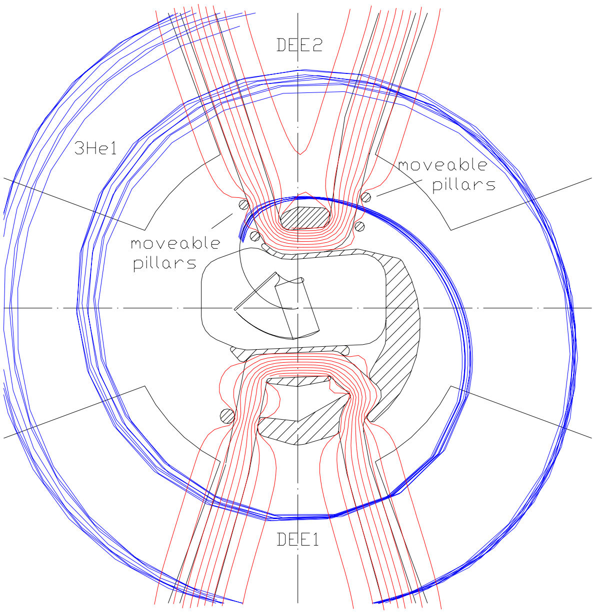

Figure 5: The first orbits trajectories of 3He1 ion beam at 4 RF harmonics, "B" mode.

To form first and second accelerating gaps the moveable ground pillars are placed at the both sides of 2nd dummy-dee. That pillars decreases the RF voltage penetration inside the dummy-dee. It is especially important for 6th harmonic mode. At the figure 7, azimuth component of electric field and RF phase of the characteristic ion are presented. Despite of the ground pillars presents, the short deceleration part of RF phase acts on the beam. Fortunately, this deceleration is not considerable for the acceleration process, figures 6 and 8.

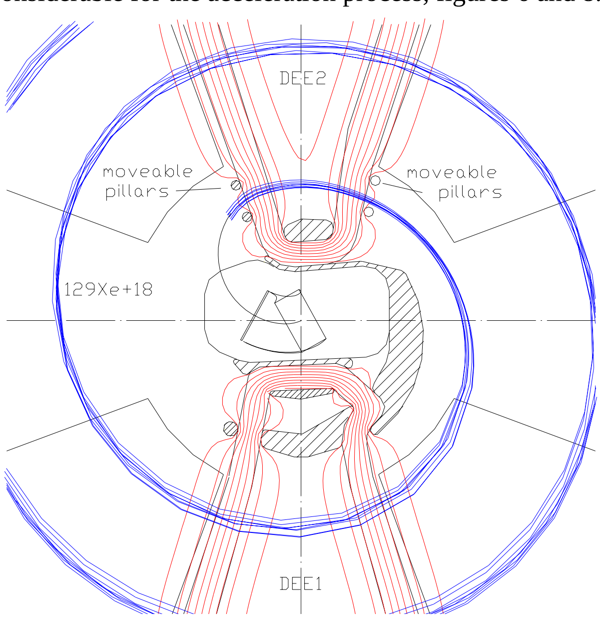

Figure 6: The first and second orbits of 129Xe+18 ion beam at 6 RF harmonics, "C" mode.

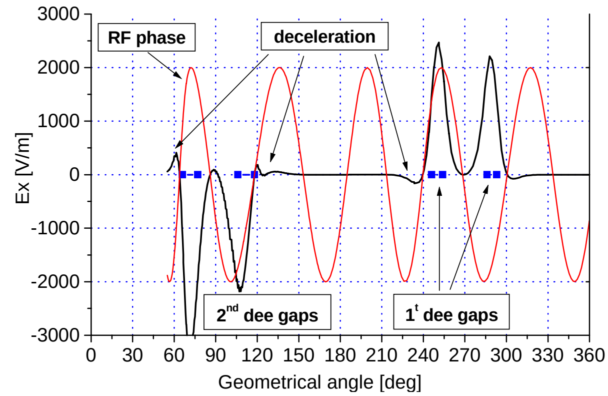

Figure 7: The RF phase and azimuth component of electric field acted on 129Xe+18 central ion.

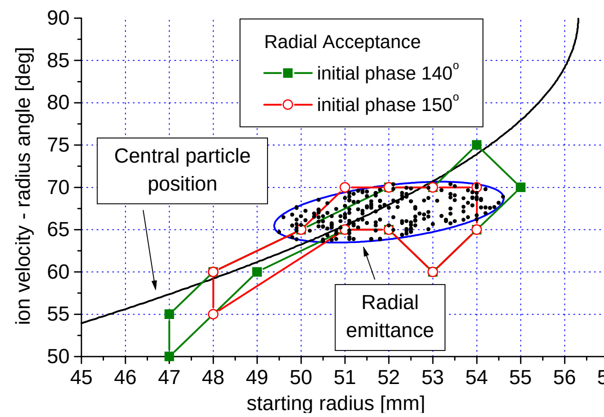

Figure 8: Radial acceptance and optimal position of the 129Xe+18 ions beam emittance.

CONCLUSION

The design of DC-72 cyclotron centre region is curried out. The peculiarity of this geometry is the three operation modes with different harmonic numbers. To optimize the first gap angular position the 2 and 3 harmonic modes starts the acceleration from 1t dee, 4, 5 and 6 harmonic modes – from 2nd dee. The separation of harmonic modes let us to cover the operating range with the stationary placed central region elements. To change the cyclotron operation modes one need only exchanging the spiral inflector and adjustment of the 2nd dummy-dee pillars position.

REFERENCES

[1] I Ivanenko, "The central region of the U-400 cyclotron. The calculation of the accelerating beam dynamics for the first orbits after injection," 15 Conference on Cyclotrons, Caen, France, June 1998.

[2] I. Ivanenko, et. al., "The compensation of beam vertical defocusing after the spiral inflector by using passive magnetic channel," EPAC'2000, Vienna, June 2000, p. 1504.

[3] B. Gikal et al., "Upgrading of IC-100 Cycle Implantator," JINR, P9-2003- 121, Dubna 2003.