MODERNIZAION OF THE U400 CYCLOTRON AT THE FLNR JINR

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Abstract

The U400 cyclotron diameter is 4 m, the K-factor is 625. The U400 has been put in operation since 1978. The stripping foil method is used to extract ion beams. The axial injection system with the ECR ion source and two bunchers (Sine and Line types) was created in the period of 1996-1998.

At present time, some cyclotron parameters can be improved. First of all it is concern of the total acceleration efficiency and possibility to vary ion energy fluently at factor 5 for every mass to charge ratio A/Z by means of changing the RF frequency and the magnetic field. The width of ion energy region will be from 0.8 to 27 MeV/nucleon. The project of U400 modernization intends decreasing the magnetic field level at the cyclotron center from 1.93÷2.1T to 0.8÷1.8T. One intends changing the construction of the axial injection. For ion extraction out of the U400, both the stripping foil and deflector methods are considered. Also, the project intends changing the U400 vacuum, RF and power supply systems.

INTRODUCTION

The isochronous U400 cyclotron has been in operation since 1978 [1]. Today, the main accelerating particle at U400 is the rare $_{48}Ca$ isotope [2] The intensity of $_{48}Ca^{+5}$ ions with energy of 260 MeV at extraction radius is about 4.3 pμA (21.5 μA). After extraction by means of the stripping foil at charge exchange rate of $Z_{out}/Z_{in}=3$, the intensity of the main spectrum line of $_{48}Ca^{+18}$, that is mainly used for physical experiments, is about 1.4 pμA (25μA). The U400 allows us to vary ion energy fluently (without decreasing the ion intensity at U400 output) at about 8% around the standard energy for given A/Z. This variation is carried out by means of changing the stripping foil position, or changing the RF frequency and the magnetic field level. Nevertheless, for some experiments the depth of the fluent energy variation is not enough.

The modernization has been suggested to improve the cyclotron parameters. The cyclotron parameters before (U400) and after (U400R) the modernization are shown in Tab.1.

The aims of the modernization are:

1. Decreasing the magnetic field level at the cyclotron center from the region of 1.93÷2.1 T to 0.8÷1.8 T, that allows us to decrease the electrical power of the U400R main coil power supply in four times.
2. Providing the fluent ion energy variation at factor 5 for every mass to charge ratio A/Z at accuracy of $\Delta E/E=5\cdot10^{-3}$;
3. Increasing the intensity of accelerated ions of rare stable isotopes at factor 3.

Table 1	U400	U400R
Parameters	**Value/Name**	
Electrical power of magnet power supply system	850 kW	200 kW
The magnetic field level in the magnet center	1.93÷2.1 T	0.8÷1.8 T
The hill angular width at the external radius	42°	43.7°
The hill gap at the external radius	42 mm	56 mm
The valley gap	300 mm	300 mm
The number of trim coils	8, radial 1, azimutal	14, radial 4, azimutal
The number of dees	2	2
The dee voltage (amplitude)	80 kV	80 kV
The A/Z range	5÷12	4÷12
The frequency range	5.42÷12.2 MHz	5.42÷12.2 MHz
Harmonic modes	2	2÷6
The ultimate extraction radius	1.72 m	1.8 m
K- factor	305÷625	100÷506
Vacuum level	$(1\div5)\cdot10^{-7}$ Top	$(1\div2)\cdot10^{-7}$ Top
Ion extraction method	Stripping foil	Stripping foil Deflector
Number of directions for ion extraction	2	2

MODERNIZATION OF MAGNETIC SYSTEM

As it was mentioned above, the modernization project intends to decrease the U400 magnetic field level from the region of 1.93÷2.1 T to 0.8÷1.8 T. Construction of the main magnet and the main coils will not be changed, but the cyclotron hills and the trim coils will be modernized.
The working diagram and energy range of possible accelerated ions for the U400R are shown in Figure 1 and Figure 2.

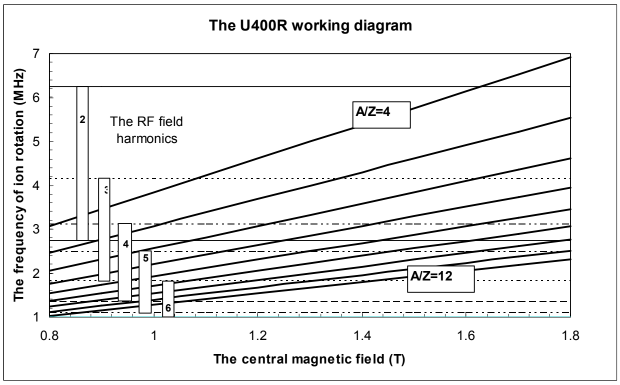

Figure 1: The U400R working diagram

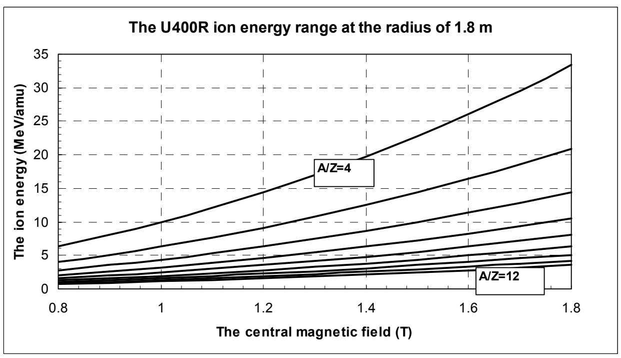

Figure 2: The energy range of possible accelerated ions

Realization of the diagram requires to create isochronous magnetic field up to the radius of 1.8 m. For the purposes, the 3-D computer model of the U400 magnet system was created in the "Syntez" NIIEFA, St-Peterburg and magnetic field calculations has been carried out. On the base of the model, step-by-step optimization of the magnetic structure and construction of trim coils has been made. The final construction of the U400R magnetic system includes plate hills with azimutal shimmes and chamfers of 45°(50×50 mm×mm) at the outer radius. The trim coils will be situated under the hills in the gap of 28 mm. The total power of the trim coil power supplies will be about 20 kW.

MODERNIZATION OF AXIAL INJECTION SYSTEM

The beginning modernization of the U400 axial injection that has been undertaken in 2002 included sharp shortening the injection canal horizontal part [2]. As the result, the distance from the ECR to the AM90 banding magnet became equal to 730 mm (Figure 3). The changes allows us to increase the $_{48}Ca^{+18}$ ion intensity at the U400 output from 0.9 to 1.4 pμA. Further modernization intends decreasing ion losses by means of increasing the SL solenoid inner diameter from 68 to 100 mm and the AM90 banding magnet horizontal aperture from 70 to 94 mm.

In according to calculation results, decreasing the U400 magnetic field demands to install two S1, S2 solenoids in the top part of the channel and one extra S3 solenoid in the bottom part to provide ion focusing at the inflector input. The S1, S2 solenoids will have total magnetic field of 0.2 T at the total effective length of 812 mm. The S3 will have the magnetic field of 0.45 T at the effective length of 134 mm.

In the future, we are planning to search possibility increasing the injection voltage from the range of 13÷20 kV to 40÷50 kV. As we estimated, the changes can give us increasing the U400R accelerating efficiency in 1.5÷2 times, it is particularly important for $_{48}Ca$ ions.

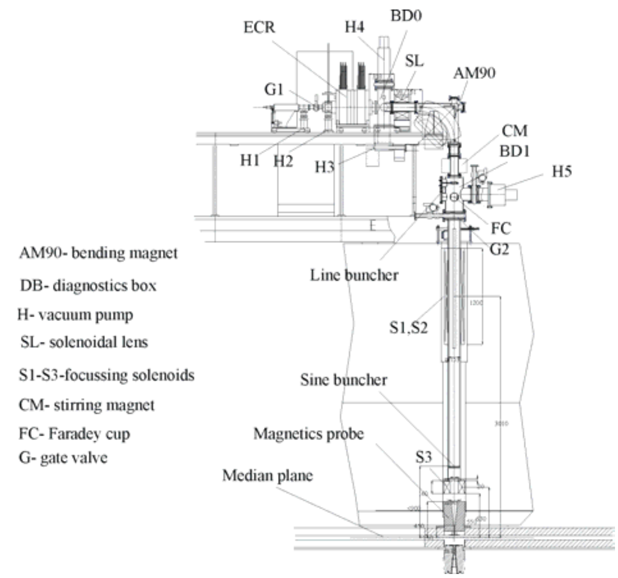

Figure 3: The U400R axial injection

MODERNIZATION OF ION EXTRACTION SYSTEM

To extract ions out of the U400R we suppose to use two ways: electrostatic deflector and stripping foil method. To estimate the extraction possibility, the numerical calculation has been carried out for ions with A/Z=4÷12. In the calculations, the magnetic field maps were used. The maps were calculated in the "Syntez" NIIEFA, St-Peterburg, the calculated results are in good accordance with experimental data.

The results of calculation the ion trajectories for the electrostatic deflector (ESD) are shown in Figure 4. It was supposed, that the average radius of the final orbit is Rav=180 cm. To deflect ion beam the deflector with the asimutal longitude of 40° (Θ=70°÷110°), situated in the vale V1 is used. The strength of the ESD electrical field is not more than 100 kV/cm. The calculation results give us two directions of extracted ions with A/Z=4 at maximal energy: with the angle between the vale axis and the extraction trajectory of ≈52° for the ion energy of Wmax=22.4 MeV/amu at the ESD field strength of Edef=94 kV/cm and with the angle of ≈83° for Wmax=25.55 MeV/amu and Edef=98 kV/cm. In the method, providing the extraction efficiency up to 80% requires the magnetic field stability at the level of

$\Delta B/B=5\cdot10^{-6}$, the RF amplitude stability of$\Delta U/U=2\cdot10^{-4}$. Besides that it is necessary or to provide the beam bunching in the faze of 5° or using the flat-top system to decrease the ion momentum spread.

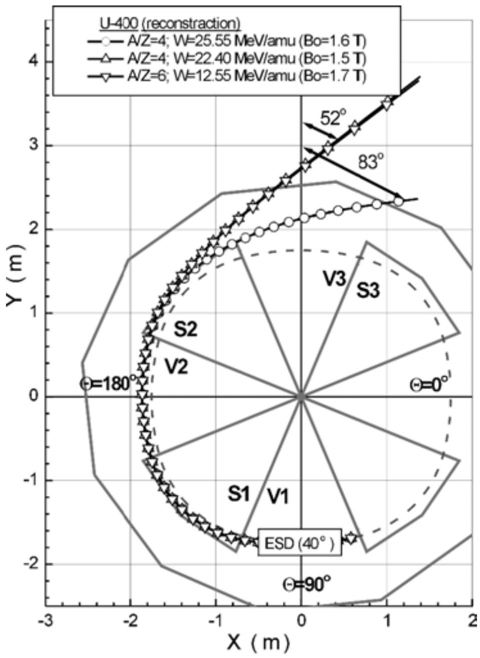

Figure 4: The scheme of the ion beam extraction by deflector in two extraction regimes

The results of numerical simulation of ion extraction by the stripping foil method shown in Figure 5. The calculations have been carried out for ions with A/Z=8, at the magnetic field levels of Bo=0.8÷1.2÷1.8 T and the charge exchange coefficients of Z_{out}/Z_{in}=2,0÷2,5÷3,0÷3,5. The beam emittances after the stripping foil taken equal to E_x=5÷10 π mm×mrad; E_z=4 π mm×mrad at the energy spread of δW=1.5%. After analyzing of the results, we decided to extract ions by mean of two separate foil probes. The first probe will extract ions with Z_{out}/Z_{in}=2,5÷3,0÷3,5 and the second one will extract ions with Z_{out}/Z_{in}=2,0÷2.5. Correspondingly, the total number of the foil probes to extract ions in two opposite directions will be 4 (2+2) pieces. The extracted efficiency of the method depends on the ion type, ion energy and extracted line in extracted ion spectrum. For heavy elements the efficiency is not more than 40%.

Both the methods allow us to extract ions in the directions of existing ion transport channels.

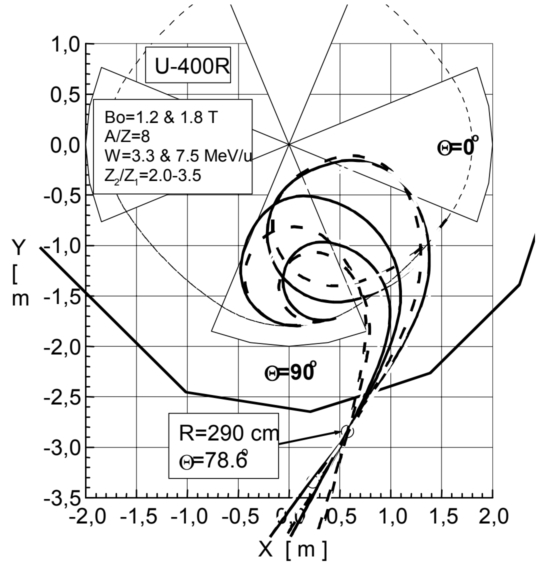

Figure 5: The scheme of the ion beam extraction by stripping foils with two separate foil probes. For B0=1,2÷1,8 T, W=3,3÷7,5 MeV/u, Z2/Z1=2÷3,5

MODERNIZATION OF RF SYSTEM

The RF system of U400R will consists of two RF generators that will excite two separated RF dee resonators. The RF resonators will be made from iron with copper coating to decrease the outgasing rate from the vacuum surface.

MODERNIZATION OF VACUUM SYSTEM

The modernization of vacuum system will include changing five diffusion pumps VA-8-7 with N_2 pumping rate of Q=4250 l/s each to five cryopumps with Q=3000 l/s each and two turbopumps with 1900 l/s each. In addition the materials of the cyclotron vacuum chamber and RF resonators will be changed to decrease their outgasing rate. The given changes allow us to improve vacuum in the cyclotron chamber from $(1.5\div2)\times10^{-7}$ Torr to 10^{-7} Torr.

REFERENCES

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[2] Yu. Ts. Oganessian, G.G. Gulbekyan, B.N. Gikal, I.V. Kalagin et al. "STATUS REPORT OF THE U400 CYCLOTRON AT THE FLNR JINR", these proceedings