MAGNETIC FIELD DESIGN AND CALCULATION FOR FLNR U400R CYCLOTRON

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Abstract

Presently FLNR reconstructs the U400 cyclotron. The new, U400R cyclotron is intended to accelerate the ion beams with A/Z from 4 to 12 up to the energy 0.78 – 27 MeV/nucleon. The wide range of the magnetic field levels from 0.8T till 1.8T allows to make a smooth variation of the beam energy over the range ± 60% from nominal. For optimization of the magnetic field the 14 pairs of radial correcting coils are used. The numerical formation of the magnetic field is carried out. At the present work the main problems and solutions of the magnetic field design are described.

INTRODUCTION

At present time, there is a plan to reconstruct the U400 FLNR, JINR isochronous cyclotron. The U400 cyclotron has a 4 – sectors magnetic structure with the 4 meter pole diameter [1]. The new, U400R cyclotron is intended for producing the beams of the accelerated ions with A/Z from 4 to 12 up to the energy 0.8 – 27 MeV/nucl [2]. The U400R cyclotron magnetic structure has ten pairs of radial correcting coils and two pairs of azimuthal correcting coils and produces the working magnetic field with the wide range of variation from 0.8T till 1.8T.

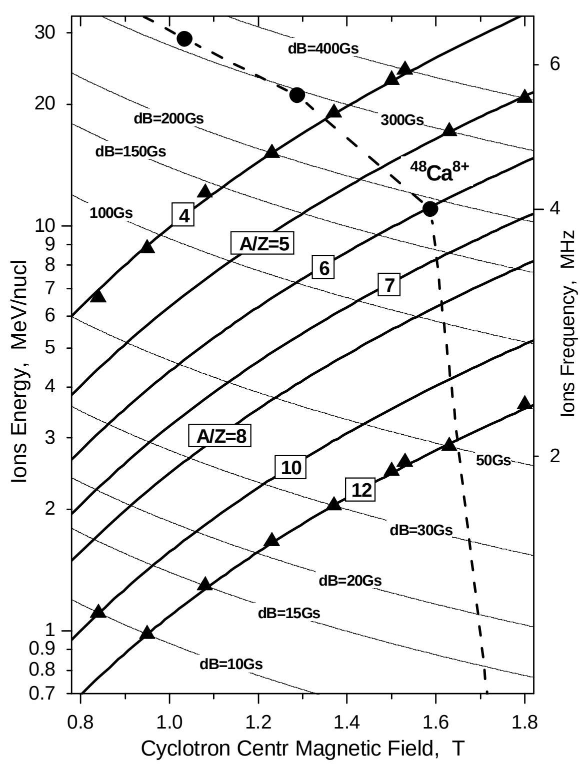

Figure 1: The working diagram of the U400R cyclotron.

The working diagram, figure 1, presents the main parameters of the U400R cyclotron. At the diagram the A/Z lines presents the isochronous accelerated modes, dB lines – corresponding radial magnetic field growth. The dash line with the circles presents the isochronous modes which can be realised with the magnetic field formed only by magnet iron of chosen geometry. Triangles point the boundary accelerated modes.

The numerical 3D simulation of U400R magnetic field was made using the KOMPOT program package [3,4]. For numerical simulation of the cyclotron magnetic field the influence functions of the variable parameters (the variation of geometry of the magnetic structure elements) were calculated. As a result the accuracy of final magnetic field numerical simulation is about 10^{-4} in the main accelerating area and is better then 10^{-3} in the magnet central region.

METHOD OF THE CYCLOTRON SECTOR SHIMMING

The three main methods of the cyclotron sector shimming are usually used to form the isochronous distribution of the cyclotron magnetic field. The sectors can be shimmed axially from the median plane side, axially from the pole side or azimuthally [5]. Then the magnetic field level is varied, the changing of the form of the field is strongly depended on the method of the sector shimming.

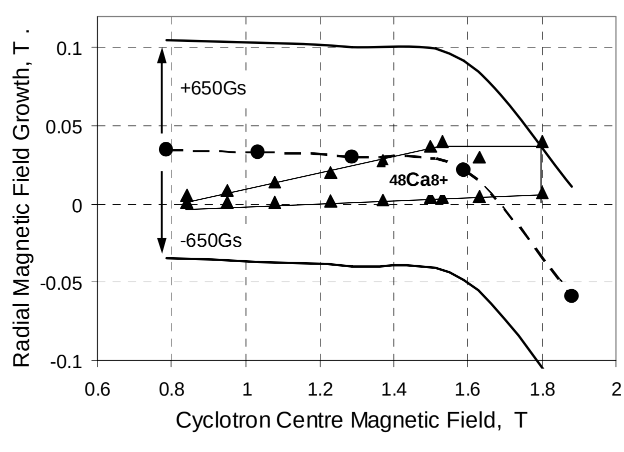

Figure 2: The working diagram area (triangle) and the real magnetic field behaviour (line with circles) of the U400R cyclotron.

In the case of the main magnetic field has a wide range of variation it is very important to choose the optimal method of the sector shimming. For the U400R cyclotron we choose the method of azimuthal shimming. It allows to optimize the magnetic field behaviour with the working diagram and to minimize the contribution of the radial trim coils.

The area of variation of the radial magnetic field growth for U400R cyclotron (according to working diagram) is presented at the figure 2 by triangles. The dash line with the cycles presents the magnetic field form, produced only by the cyclotron magnet iron with the azimuthal shimming of the sectors. The matching of the triangle area and line determine the working modes then the isochronous magnetic field is formed without trim coils. Other working modes need the correction with the trim coils. According to the figure 2 the optimal contribution for radial trim coils no more then ±650Gs for all accelerating modes of the U400R cyclotron.

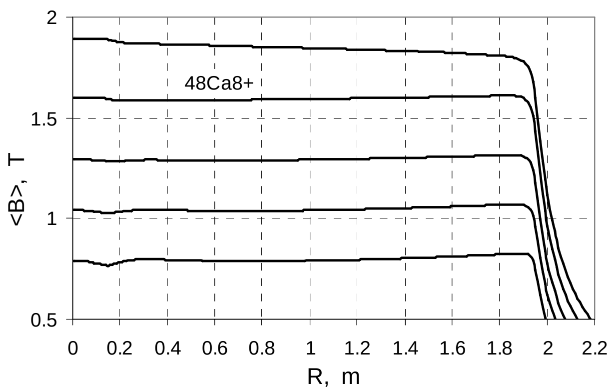

Figure 3: The results of final calculation of U400R cyclotron average magnetic field.

We choose the nominal working point with the centre magnetic field 1.6T as a base point for numerical simulation and formation of the magnetic field, figures 1 and 2. At this point the beam of ions 48Ca8+ will be accelerated to the energy 11MeV/nucl in the isochronous magnetic field formed only by magnet iron, figure 3.

THE RADIAL TRIM COILS

To form the isochronous accelerating modes, presented by the working diagram, the U400R cyclotron has ten radial trim coils. We choose the low power construction of the coils. The maximum power consumption of all ten coils with the current 20A is no more then 12kW. Each coil has 78 turns or 1560 A·turns. It is enough to produce the required sum contribution of the coils ±650Gs to form the accelerating modes of the U400R cyclotron and additional ±100Gs for thin additional correction of the magnetic field. At the figure 4 the sum contribution of the ten radial trim coils with 20A current supply at the average magnetic field level 1.8T is presented.

For optimization of the coils contribution it is convenient to use the formula of the coil radial position:

$$R_i = R_{\max}\sqrt{\frac{i}{N_{\max}}} \tag{1}$$

where N_{max} and R_{max} denotes number and maximal radius of radial trim coils, $i=1 \,..\, N_{max}$.

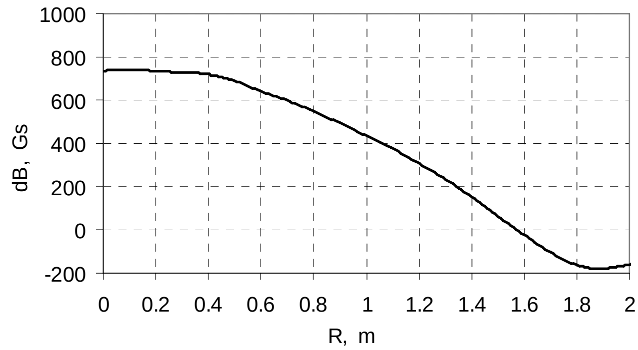

Figure 4: The sum contribution of the ten radial trim coils at the average magnetic field level 1.8T.

The radial position of the trim coils according to the formula 1 provide the form of the additional magnetic field which is most optimal for operative formation of the cyclotron accelerating modes.

Table 1: The parameters of the U400R radial trim coils with the maximal current 20A

№ coil	Radius, mm	Voltage, V	Power, Wt
1	571	13	265.9
2	807	19	376.0
3	989	23	460.5
4	1142	27	531.7
5	1276	30	594.5
6	1398	33	651.2
7	1510	35	703.4
8	1614	38	751.9
9	1712	40	797.6
10	1805	42	840.7

MAGNETIC FIELD AT CENTRE REGION

While the magnetic field is varied in a wide range of levels it is very important that the form of the field change uniformly. Nevertheless different regions of the magnetic structure have a different levels and a different rate of changing of magnetic saturation. Especially it is dramatic at the cyclotron central region.

Thus the formation of the magnetic field at cyclotron centre region consists of two interrelationship problems:

- formation of the isochronous form of the magnetic field at the nominal working point
- formation of the conditions when the rate of changing of magnetic field form at the centre will be closed to the rate of changing of magnetic field form in the whole working area of cyclotron.

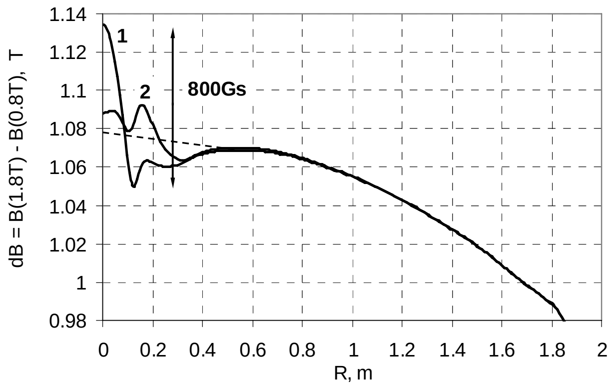

Figure 5: The difference of the average magnetic field at the high, 1.8T and low, 0.8T levels.

The magnetic field at cyclotron centre can be formed by changing the geometry of centre plug and noses of sectors. We found that the form and diameter of the axial hole of the centre plug have dramatic effect on the rate of changing of magnetic field form at the centre when the field level is varied in the range 0.8T – 1.8T. At the figure 5 the difference of the average magnetic field at 1.8T and 0.8T levels is presented. The dash line presents the "ideal" uniform changing of the field at the centre.

At the figure 6 the customary form of the axial hole of the cyclotron centre plug is presented. The diameter of the hole is small and varied from 20mm near the centre to 80mm. At this case the amplitude of nonlinear behaviour of changing of the magnetic field at the centre runs up to 800Gs, line 1 at the figure 5. Because of the nonlinearity a bump or a hole of the centre region field will appear when the field level is varied from 0.8T to 1.8T.

To decrease the amplitude of nonlinearity, the axial hole diameter of the centre plug was increased to 50mm near the centre and 100mm at the main hole, figure 7. This lead to reducing the amplitude of nonlinearity more then tree times, line 2 at the figure 5.

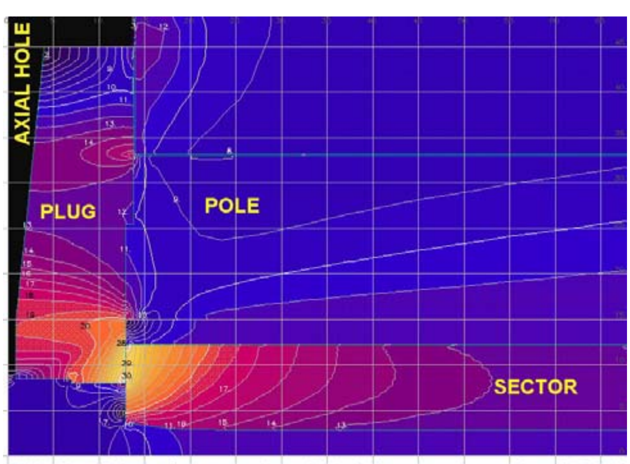

Figure 6: Magnetic field distribution in the vertical section of the magnet centre region with the small diameter of plug axial hole.

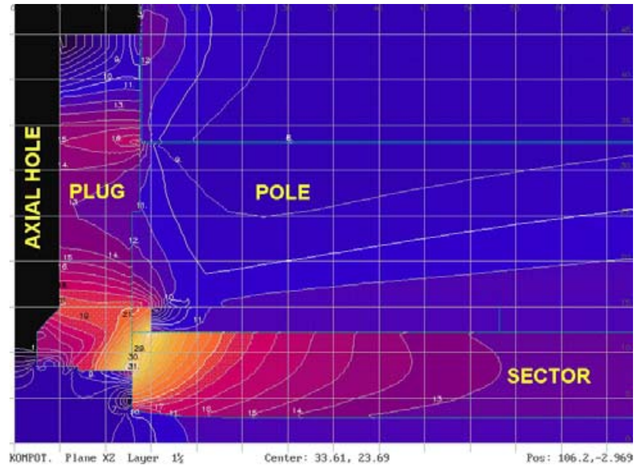

Figure 7: Magnetic field distribution in the vertical section of the magnet centre region with the big diameter of plug axial hole.

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