ISBN: 978-3-95450-202-8 doi:10.18429/JACoW-HB2018-THP2WC03

THE CHOOSING OF MAGNETIC STRUCTURE OF ISOCHRONOUS CYCLOTRON DC-130 FOR APPLIED RESEARCHES

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Abstract

At the present time, the activities on creation of the new multipurpose isochronous cyclotron DC130 are carried out at the FLNR, JINR. The cyclotron DC130 is intended for microchip testing, production of track pore membranes and for applied physics. The cyclotron will accelerate the heavy ions with mass-to-charge ratio A/Z from 5 to 8 up to the fixed energies 2 and 4.5 MeV per nucleon. The main magnet and acceleration system of DC130 are based on the U200 cyclotron that now is under reconstruction. At the present paper, the method of choosing of main magnet parameters of cyclotron is described.

INTRODUCTION

The main direction of scientific program of Flerov Laboratory of Nuclear Reactions of Joint Institute for Nuclear Research (FLNR JINR) is the synthesis of heavy and exotic nuclei. Furthermore, the different applied researches and acceleration technology investigation are carried out. Total operating time of FLNR cyclotrons reach more than 16000 hours per year and continue to growth. At the present time the activities on creation of the new dedicated cyclotron DC130 for applied researches are carried out. The main usage of the new cyclotron will be the track pore membrane production and microchip testing [1]. DC130 will be created as a deep reconstruction of the old cyclotron U200.

U200 CYCLOTRON

U200 isochronous cyclotron had been in operation at FLNR, JINR, since 1971 and provided the production of nuclear beams with $A/Z=3\div5$ at energies up to 9 MeV/nucleon [2]. The cyclotron magnet has H – type yoke and produce magnetic field up to 2T. Two-meter diameter pole and four pairs of straight sectors form the isochronous and focusing conditions for acceleration. Two 45-degree-dees of RF accelerating system are placed in the opposite valleys between the sectors. Main parameters of the magnet are presented in Table 1. At a present time U200 cyclotron is decommissioned and prepared to reconstruction to the new cyclotron DC130.

NEW DC-130 CYCLOTRON

The new multipurpose cyclotron DC130 is intended for different tasks of applied researches. The main activities will be in the microchip testing and production of track pore membranes. For microchip testing, the heavy ions from Ne up to Xe and Bi with the fixed energy 4.5 MeV/nucleon will be available. For that activities it will be possible to accelerate ions with mass to charge ratio from 5 to 5.5, for example 20Ne4+, 209Bi38+. The beams will be accelerated on the 2 harmonic of RF with the fixed frequency 10.622MHz of RF generator.

Table 1: Main Parameters of U200 / DC130 Magnet

Parameter	Value
Main size of the magnet, mm	5000x2100x3600
Diameter of the pole, mm	2000
Distance between the poles, mm	150 / 160
Number of the sectors pairs	4
Sector angular extent (spirality)	43° (0°)
Sector height, mm	46 / 45
Distance between the sectors (magnet aperture), mm	30
Distance between the sector and pole (for correcting coils), mm	14 / 20
Number of radial coils	6
Maximal power, kWt	≈300

The production of track pore membranes will be based on the intensive beams of heavy ions from Ar to Bi with the fixed energy 2 MeV/nucleon. The mass to charge ratio varies from 7.58 to 8, for example 197Au26+, 40Ar5+. The frequency of RF generator for that operation mode will be the same, 10.622MHz, but the beams will be accelerated on the 3 harmonic of RF.

The operation mode substitution will be implemented only by changing the level of the magnetic field in the wide range from 1.729T to 1.902T and its isochronous distribution will be formed operationally by means of six radial correcting coils.

In the frame of reconstruction of U200 to DC130 it is planned to upgrade the cyclotron magnetic structure, replace the magnet main coil and renovate RF system. Other systems, axial injection, beam extraction, vacuum, cooling, control electronics will be new.

MAGNETIC FIELD FORMATION

The compact type magnet of the old, U200 cyclotron will be upgraded to accelerate in new operation modes. The deep reconstruction of the magnet means that the yoke will stay the same, but dimensions of working area, sectors, shims and central plug must be changed. The diameter of the pole is fixed by the yoke dimension and equal 2 meters. The pole diameter and the beams energy define the levels of the isochronous magnetic field at the cyclotron center from 1.729T to 1.902T. 160mm gap between the upper and lower poles was chosen as a compromise between field level and magnet aperture. Four pairs of straight, 43-degrees sectors form the isochronous and focusing conditions

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for the beam acceleration. The sectors height is 45mm. 20mm gap between pole and sector is fixed for placing of the correcting coils. 30mm gap between the sectors will be enough for beam transmission without aperture losses. The chosen parameters form the azimuth variation of the magnetic field and provide the needed focusing properties with betatron oscillations Qr=1.01 and Qz=0 - 0.3.

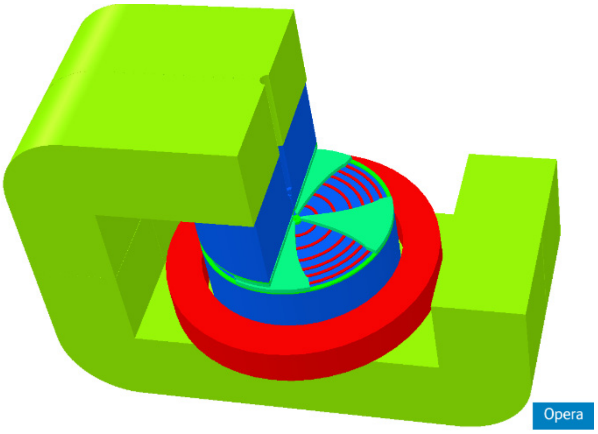

Figure 1: DC130 magnet computer model.

The first step of magnetic field formation, the computer modelling, is held with TOSCA code. The model of the magnet was created on the base of U200 cyclotron drawings (Fig. 1). The second step will be a final formation during the magnetic field mapping. For that, a removable shim as a part of magnetic structure will be used.

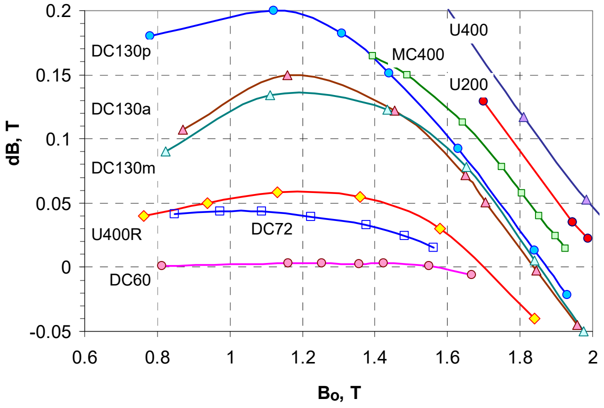

Figure 2: dB(B) functions for operated and projected FLNR cyclotrons.

The important parameter to form of the multi-particle cyclotron magnetic field is a dB(B) function, there dB is a radial growth of the magnetic field in dependence of the field level. dB(B) function has an original behaviour for each cyclotron magnetic structure and depends on dimensions and shape of the elements of magnet, saturation property of the metal. In Fig. 2, dB(B) functions for some FLNR cyclotrons are presented [3].

For multi-particle cyclotron, the dB(B) functions of the magnet may not coincide with the isochronous growth of the magnetic field of some operation modes. Furthermore, at the same level of magnetic field, the operation modes with different dB could be used. At this case, the isochronous field for each mode is formed operatively by means of correcting coils. The goal of the computer modelling is to find the optimal shape of the magnet structure to minimize the power of correcting coils.

The formation of cyclotron magnetic field can be carried out by shaping of sector profile as axially, and azimuthally. In the frame of optimization of DC130 magnet, the three methods of sector shaping were investigated.

The first and more commonly used method is a changing of sector azimuthal profile. At this case, the machining and placing of the sector is easier technologically. To achieve the isochronous distribution, the azimuthal profile of DC130 sectors must be cut from both sides by curved line with a deep up to 54mm. That complicate the use of removable sector - edge shims. The behaviour of corresponding dB(B) function is presented in Fig. 2 as DC130m line.

The second method is a shaping of the sector height from the cyclotron median plane side. At this case, the sector edges stay straight, that is convenient for placing of removable shims. The disadvantage of this method is a very high sensitivity of magnetic field to the accuracy of machining of sector surface. Sharp edges of the surface profile lead to local field perturbations. For DC130 this sensitivity is about 60Gs/mm and highly depends on the radius. It means that the machining of the surface must be smoothed by curves or many small steps It is rather complicated and expensive. The corresponding dB(B) function is presented in Fig. 2 as DC130a line.

The third method is a shaping of the sector height from the pole side. Because the shaped surface is closed from cyclotron median plane by sector itself, the sector could be machined more roughly by small number of steps with height of 5 – 10 mm (Fig. 3) and the field distribution will stay a smooth. The corresponding dB(B) function is presented in Fig. 2 as DC130p line.

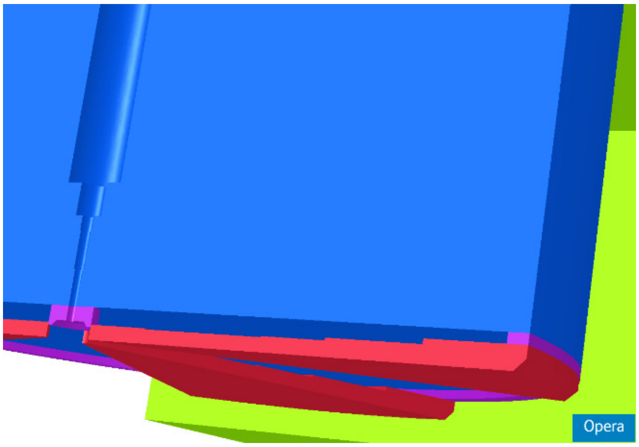

Figure 3: The shaping of DC130 sector height from the pole side.

The disadvantage of this method is an arising of magnetic force of attraction between upper and lower sectors in the case, when the gap between pole and sector more than gap between the sectors. For DC130 the gap between sectors is 30 mm. The calculations shown that the noses of

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sectors, where gap between sector and pole is 38 mm, are attracted one to another with 13000N. The outer parts of sectors, where gap between sector and pole is 20 mm, are attracted to the poles with the force about 15000N.

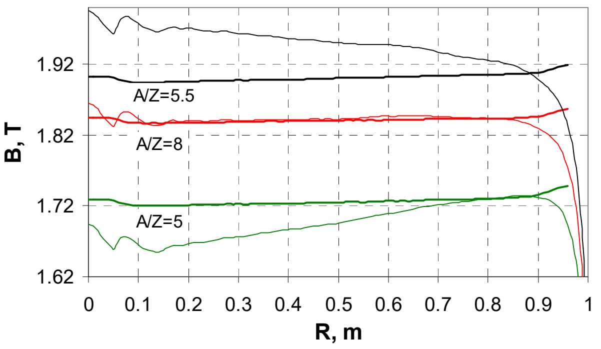

Figure 4: The isochronous and real magnetic field for characteristic operation modes. The sector is shaped by height from the pole side.

In Fig. 5, the lines present dB(B) dependence of real magnetic field for three methods of DC130 sector shaping. Dots present the value of radial growth of isochronous fields for some characteristic operation modes. The difference between the real and isochronous magnetic field will be compensated by radial correcting coils. The degree of correction could be estimated as +- 500Gs for operation modes with lower 1.729T and higher 1.902T magnetic field levels.

For DC130 the shaping of the sector height from the pole side was chosen as more convenient for sector machining and for placing the removable shims on the straight edges of sectors. Furthermore, from Fig. 4, the operation mode for acceleration of ions with A/Z=8 is chosen as nominal, where isochronous magnetic field will be formed only by metal, without use of correcting coils.

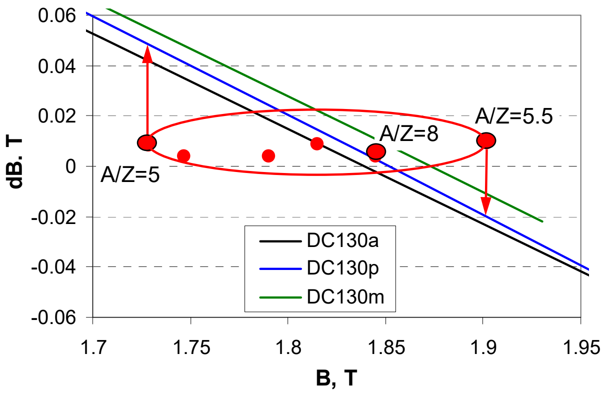

Figure 5: dB(B) functions for three ways of sector shaping and characteristic operation modes.

For DC130 cyclotron magnet the two methods to form the magnetic field at the extraction radius are used. The first one is the chamfer 20x20mm at the outer edge of the sector, see Fig. 3. The chamfer lifts the average field and kick up the flatter at the extraction radiuses, Figs. 6 and 7.

The second one is the ring shim, that is placed between sector and pole at the outer radiuses 960 – 1000 mm. The ring shim lifts the field, especially at the "valley" between the sectors, that leads to decreasing of the flatter. The use of both methods give the increasing of the beam final energy and efficiency of extraction. Furthermore, the use of both methods gives the compensation of the flatter growth and lets to avoid the dangerous resonances at the last orbits.

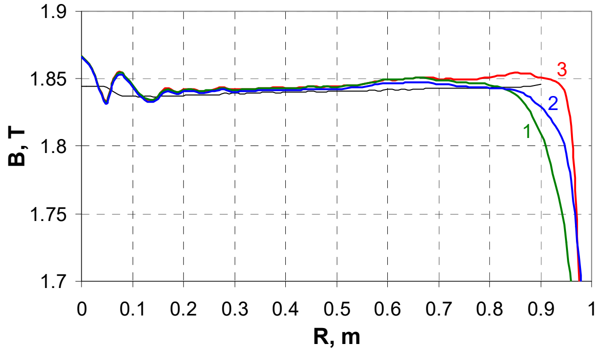

Figure 6: Average magnetic field for cases: 1 – without ring shim and chamfer; 2 – with ring shim; 3 – with ring shim and chamfer.

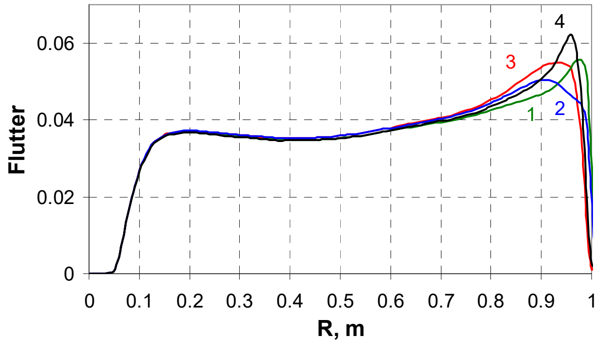

Figure 7: Flutter for cases: 1 – without ring shim and chamfer; 2 – with ring shim; 3 – with ring shim and chamfer; 4 – with chamfer.

RADIAL CORRECTING COILS

To form the isochronous magnetic field for different acceleration modes the radial correcting coils will be used. The coils compensate the difference between isochronous and real magnetic fields. According to Fig. 5, the level of the field compensation must be up to +-500Gs for the operation modes with lower 1.72T and upper 1.902T magnetic field levels. For nominal operation mode, acceleration of ions with A/Z=8 at Bo=1.8T, the real magnetic field is formed as isochronous by metal only, and the correcting coils are not uses. The other goal of radial coils is to correct the beam phase shifting, that arises due to the local magnetic field perturbations. For that purpose, about +-100Gs of correction field is enough. The third, additional goal is a correction of possible median shifting of the beam. This shifting could be corrected by means of radial component of magnetic field. To produce Br component, the last coil has two separate power supplies for upper and lower subcoils. As a result, DC130 cyclotron magnet must be equipped with radial coils for producing +-600Gs of correction magnetic field. The coils will be placed in the 20mm gap between pole and sectors.

The number of radial coils is chosen as a compromise between the cost of manufacturing and exploitation and, the accuracy of magnetic field correction. For DC130 cyclotron the 5 radial coils are placed according Eq. (1).

$$R_n = \frac{R_k}{\sqrt{k}} * \sqrt{n} \qquad (1)$$

where n=1…5 is a number of coil, Rk=900mm – radius of the last coil with k=5.

The additional coil for field correction at the centre is placed at the radius 220mm. In Fig. 8, the positions and field contributions of DC-130 radial coils with 50A current supply is presented.

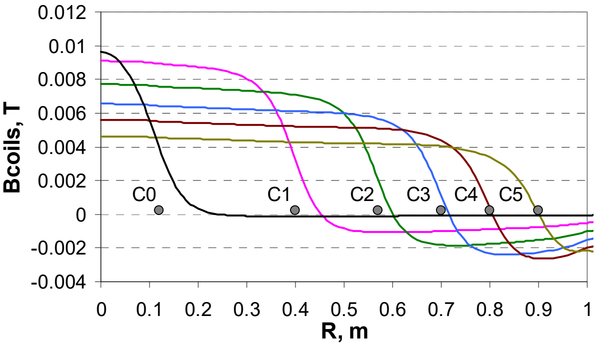

Figure 8: The positions and contributions of the radial coils at the average magnetic field, level 1.729T.

The results of computer formation of test operational modes at the lower, 1.729T, nominal, 1.845T, and higher, 1.902T, levels of magnetic field are presented in Figs. 9, 10 and 11. At figures the “formed field” means the result of correction of the base magnetic field with usage of radial correcting coils. The criteria for the correction is the minimization of the “beam phase” deviation during acceleration. As a result, the phase shifting of accelerated beam at the “formed” magnetic field is no more than ±10° for operational modes at lower and higher levels of magnetic field and about ±2° for nominal operational mode. The computer formation of the test operational modes, define the needed maximum of the radial coils power consumption as 1500A*turn. For that, the high current coils with 5 turns and 300A of current supply could be used The wire with 10x10mm cross-section and inner d5mm hole for cooling is chosen. The alternative is a low current coils with 60 turns and 26A of current supply. At this case, the wire has 2x7mm cross-section and coils are placed in a cooled aluminium box.

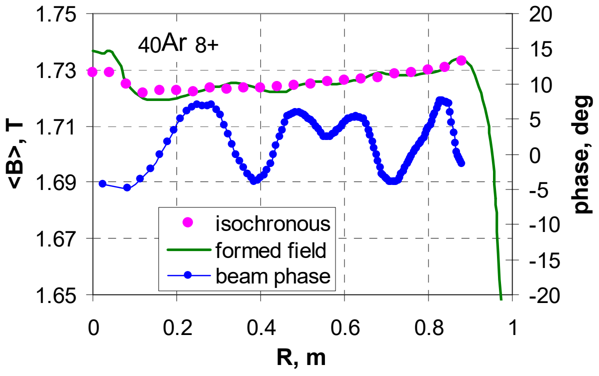

Figure 9: The isochronous and formed magnetic field for 40Ar8+ acceleration mode.

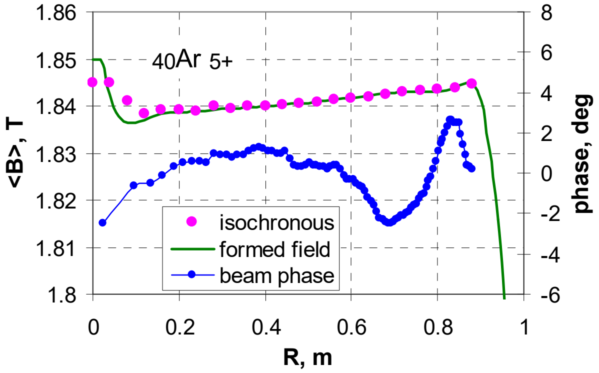

Figure 10: The isochronous and formed magnetic field for 40Ar5+ acceleration mode.

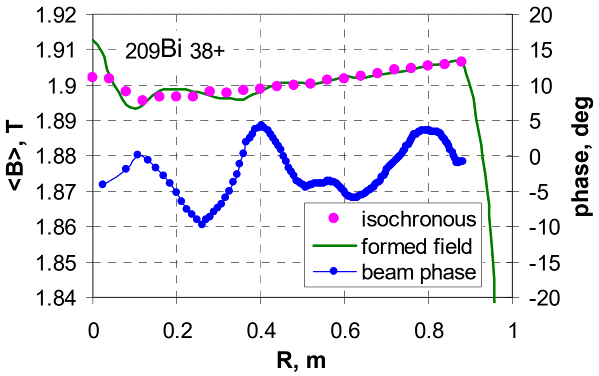

Figure 11: The isochronous and formed magnetic field for 209Bi38+ acceleration mode.

CONCLUSION

At the present time, the project of DC130 cyclotron is at the design stage. New cyclotron is intended for applied applications only. The main activity, 6000 hours per year, will be in microchip testing, production of track pore membranes and different applied researches. The criteria of choosing of magnetic structure is a compromise between the costs of manufacturing and exploitation. The cyclotron will provide the fast changing and the optimal parameters for wide range of the given operational modes.

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