THE FEATURE OF MAGNETIC FIELD FORMATION OF THE MULTI-PURPOSE ISOCHRONOUS CYCLOTRON DC-280

B.Gikal, G.Gulbekian, I.Ivanenko#, JINR, Dubna, 141980, Russia
V.Kukhtin, E.Lamzin, S.Sytchevsky, ERIEA, St. Petersburg, 189631, Russia

Abstract

At the present time the activities on creation of the new heavy-ion isochronous cyclotron DC280 are carried out at Joint Institute for Nuclear Research [1]. The isochronous cyclotron DC-280 will produce accelerated beam of ions A/Z= 4 – 7 with a smooth variation of the beam energy W= 4 – 8 MeV/n. The variation of energy is provided by the wide range of the magnetic field levels from 0.64T till 1.32T and usage of the 11 radial and 4 pairs of harmonic correcting coils. In the work the results of calculations and final measurements of the magnetic field are presented. The magnetic field of cyclotron DC-280 is formed in a good conformity with results of computer modeling.

INTRODUCTION

The main parameters of the DC-280 cyclotron are presented at the operating diagram, figure 1.

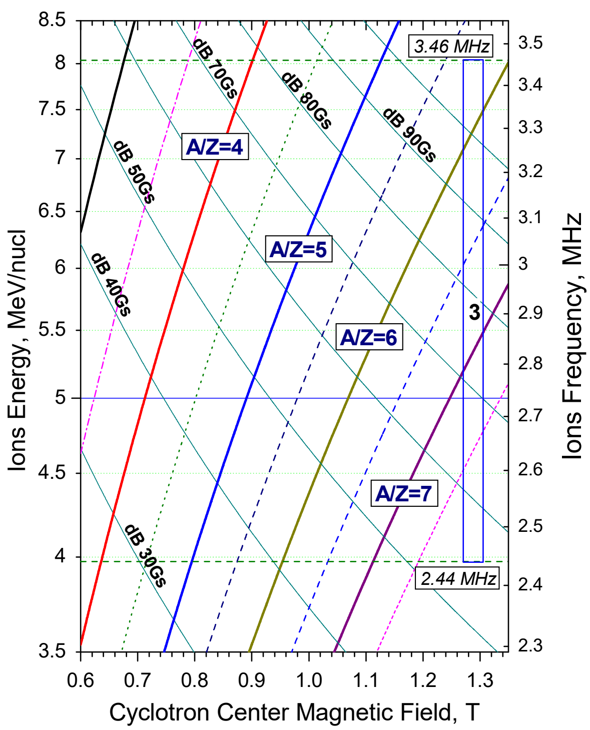

Figure 1: The operating diagram of DC-280 cyclotron.

At the diagram the A/Z lines presents the isochronous acceleration modes, dB lines – corresponding radial magnetic field growth from cyclotron centre till extraction radius 1.78m. Cyclotron acceleration system uses third RF harmonic mode.

DC-280 has a H-shape main magnet with 4 meter pole diameter. Four pairs of straight, 45-degrees sectors form the isochronous field. The wide range of the magnetic field levels from 0.64 till 1.32 T allows making a smooth variation of the beam energy in the range 4 – 8 MeV/nucleon. For operational optimization of the magnetic field the 11 radial correcting coils are used. Four pairs of harmonic coils correct the beam parameters before extraction by electrostatic deflector. The vertical gap between the sectors in 208mm was chosen for placing two dees of flat-top RF system.

Table 1: Main Parameters of DC-280 Cyclotron Magnet

Main size of the magnet, mm	8760×4080×4840
Weight of the magnet, t	1100
Maximal power, kWt	≈ 280
Diameter of the pole, mm	4000
Distance between the poles, mm	500
Number of the sectors pairs	4
Sector angular extent (spirality)	45^o (0^o)
Sector height, mm	111
Distance between the sectors (magnet aperture), mm	208
Distance between the sector and pole (for correcting coils), mm	35
Number of radial coils	11
Number of azimuthal coils	4

DC280 MAGNETIC FIELD FORMATION

For numerical 3D formation of DC-280 magnetic system the KOMPOT program package was used [2, 3].

The magnet yoke parameters were chosen to stay the magnetic field inside yoke elements not more then 1.5 – 1.6 T. At this case, the efficiency of the magnetic system stays in linear area and the fringe fields near the magnet have an acceptable level. With the usage of the magnetic shield for injection line platform the fringe fields near ECR ion source and horizontal elements of beam transport line are not more than 40Gs.

The magnetic structure of DC280 cyclotron was created with steel-10. For magnetic field calculations the real steel magnetic properties of different parts of cyclotron magnet were measured and used, Fig. 3.

#ivan@jinr.ru

Cyclotron magnetic field was formed by means of sectors, magnetic elements of centre and valley shims. The deviation of magnetic fields from isochronous can be corrected by means of radial trim coils.

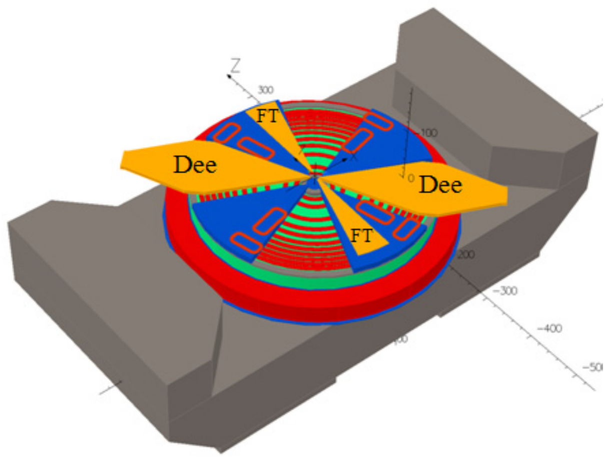

Figure 2: The model of DC-280 magnetic system.

The 11 radial correcting coils are placed between pole and sectors, Fig. 2. Each coil has 2×78 turns with maximal current 25A. The 3[th] and 10[th] radial coils have a separate power supplies for upper and lower sub coils and could be used for correction of the beam vertical position.

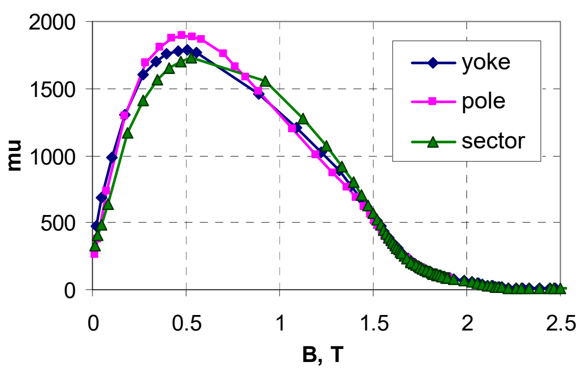

Figure 3: DC280 steel magnetic properties.

Four pairs of azimuhal coils are intended for correction of first harmonic of magnetic field and for adjust the beam orbit centring. Azimuthal coils are placed on the sectors at the side of median plane, Fig. 2. One pair of azimuthal coils can create up to 0.0025T of amplitude of the first harmonic. Two pairs of azimuhal coils are placed perpendicular one to another in two rows at radiuses R=1.5m and R=1.78m.

At Figs. 4, 5 and 6 the examples of formation of operational modes for lower, nominal and upper levels of magnetic field are presented. At figures the "formed" field means the result of correction of the base magnetic field with usage of radial coils. The criteria of 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 not more then ±4° for operational modes at lower and nominal levels of magnetic field and about ±15° for operational modes at upper level of magnetic field.

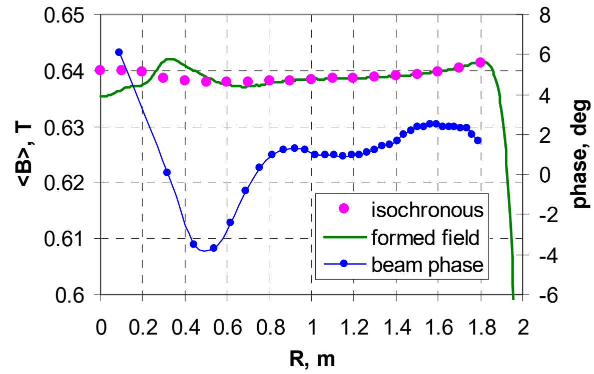

Figure 4: The isochronous and formed magnetic field for 16O4+ acceleration mode.

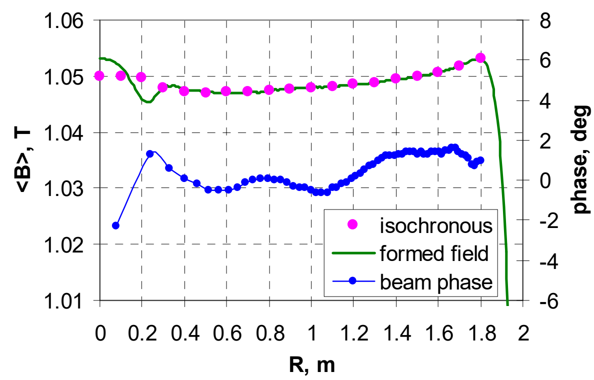

Figure 5: The isochronous and formed magnetic field for 48Ca8+ acceleration mode.

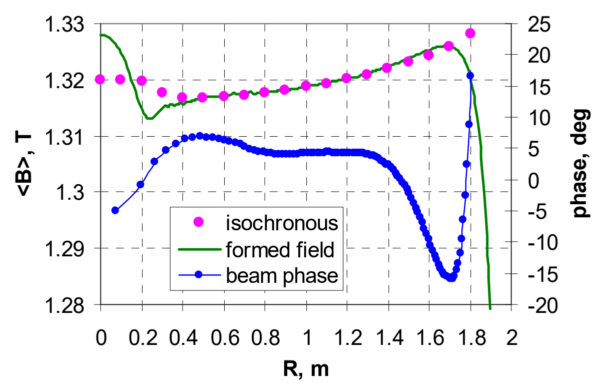

Figure 6: The isochronous and formed magnetic field for 238U40+ acceleration mode.

MAGNET CENTRE REGION

Because the magnetic field of DC280 cyclotron is varied in a wide range from 0.64T till 1.32T, the different elements of magnetic structure are saturated unevenly. It leads to a non uniform changing of magnetic field for its different levels. It is especially dramatic for the central region, compare Figs. 4 – 6.

ISBN 978-3-95450-182-3

The criterion of optimisation of this problem is a form of the difference between the average magnetic fields at high, 1.32T and low, 0.64T levels. The smaller the deviation of this difference from flat line, the better. During optimisation of the center elements (sector noses, centre plugs and shims) the minimum of deviation of this difference from the flat line was founded, Fig. 7. The difference of formed field at the centre from isochronous can be partially compensated by trim coils.

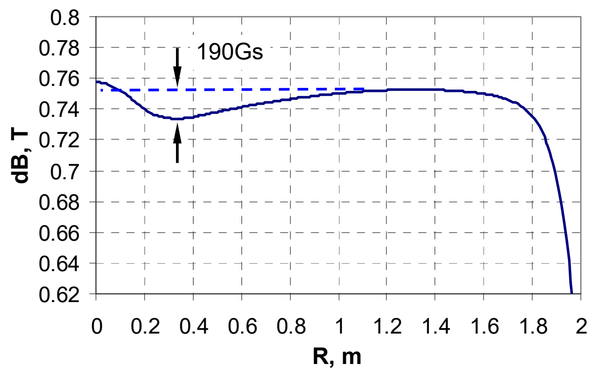

Figure 7: The difference between the average magnetic fields at the high, 1.32T and low, 0.64T levels.

MAGNET ASSEMBLING

At the present time the DC280 magnet is assembled at the vault of the new laboratory building, figure 8. After assembling the main dimensions of the magnet working area were measured, Table 2. The accuracys of assembling are close to the project parameters.

For final magnetic field formation the DC280 magnet is equipped with removable shims. There are sectors and central plug shims. The sectors shims are placed at the both sides of each sector. The sectors shims has the form of straight plates with 10-mm wide and are intended for final correction of the average magnetic field and first harmonic. The plug shims are intended for correction of the magnetic field at the centre radiuses up to 200 mm.

Table 2: The Accuracy of Assembling of DC280 Magnet

Measured value	deviation
upper and lower poles axises	0.5mm
pole to pole gap	0.4mm
upper - lower sectors gap	0.35mm
Angular summetry of upper and lower sectors	$\leq 0.15^{o}$

MAPPING SYSTEM

For final magnetic field formation the DC280 mapping system, Fig. 9, was created [4]. The mapping system is based on 14 Hall probes and measure the magnetic field in a polar coordinate system with accuracy 10^{-4}. The Hall probes are placed on the plank that is moved radially along magnetometer bar with a step 10mm. The radial range of the plank motion is 160mm. Than the map maximal radius is 160mm*14 = 2240mm. The usage of 14 probes decreases a time of mapping: the mapping of full azimuth range with 1^{o} azimuthal and 10mm radial steps take about 7 hours. The 90^{o} range mapping with 2^{o} and 20mm steps will take about 1 hour.

Figure 8: DC-280 magnet after assembling.

The mapping and final formation of DC280 magnetic field will start at the end of May 2017 and will take about 3 month.

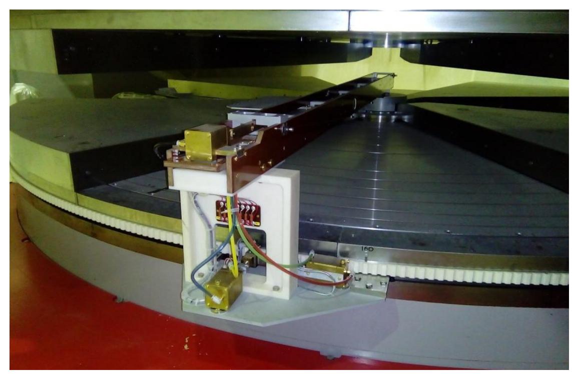

Figure 9: DC280 magnetometer with toothed belt.

REFERENCES

[1] G.Gulbekian *et al.*, "Status of DC280 cyclotron project", in *Proc. CYC2016*, Zurich, Switzerland, September 2016.
[2] B.Gikal *et al.*, "The method and results of formation of the DC-60 cyclotron magnetic field", in *Proc. Cyclotrons 2007*, Giardini Naxos, Italy, October 2007.
[3] B.Gikal, *et al.*, "The procedure and results of magnetic field formation at the cyclotron with the magnetic channel of the beam extraction system", in *Proc. ECPM 2012*, PSI, Switzerland, May 2012.
[4] I.Ivanenko, *et al.*, "Measuring system for FLNR cyclotrons magnetic field formation", in *Proc. RuPAC-16*, St. Petersburg, Russia, November 2017.