MAGNETIC FIELD DESIGN AND CALCULATION FOR FLNR DC-280 CYCLOTRON

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Abstract

The isochronous cyclotron DC-280 is intended to accelerate the ion beams with A/Z from 4 to 7 up to the energy 8 – 4 MeV/nucleon. The wide range of the magnetic field levels from 0.64T till 1.32T allows to make a smooth variation of the beam energy over the range ± 50% from nominal. For operational optimization of the magnetic field the 11 radial and 4 pairs of harmonic correcting coils are used. The numerical formation of the magnetic field is carried out. The problems and solutions of DC-280 magnetic field design are described.

INTRODUCTION

The new isochronous cyclotron DC-280 is now under construction in Laboratory of Nuclear Reactions (FLNR, JINR, Dubna). The cyclotron is intended for accelerating the beams of heavy ions from Carbon to Uranium of the energies from 4 to 8 MeV/nucleon [1]. The cyclotron has a H-shape main magnet with 4 meter pole diameter. The magnetic structure allows to carry out the smooth adjustment of the beam energy over the range ± 50 % from nominal by means of variation of the average magnetic field level at the range from 0.64T till 1.32T. The isochronous field is formed by 4 pair of 45-degrees sectors The operational correction of the magnetic field is realized by means of 11 radial and 4 pairs of harmonic correcting coils. The betatron frequencies lies on the range 1.005<Qr<1.02 and 0.2<Qz<0.3.

Table 1: Main parameters of the DC-280 cyclotron

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

NUMERICAL FORMATION OF DC-280 CYCLOTRON MAGNETIC FIELD

The numerical 3D formation of DC-280 magnetic field was made in some stages using the KOMPOT program package [2-4]. At the first stage the optimization of magnet yoke was carried out. The criteria of optimization is the magnetic field inside yoke elements should not exceed 1.5 – 1.6 T. In this case the efficiency of the magnetic system stays in linear area, figure 2.

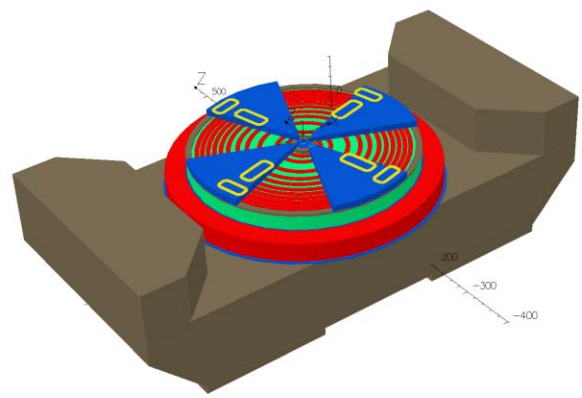

Figure 1: The model of DC-280 magnetic system.

The important problem of DC-280 magnet yoke optimization was the decreasing of the fringe field level over the magnet, where ECR ion source and axial injection line are placed. The special form of the upper (and lower for symmetry) balk of yoke and usage of the magnetic shield platform lets to decrease the fringe field down to acceptable level about 40Gs near ECR ion source and horizontal elements of beam injection line.

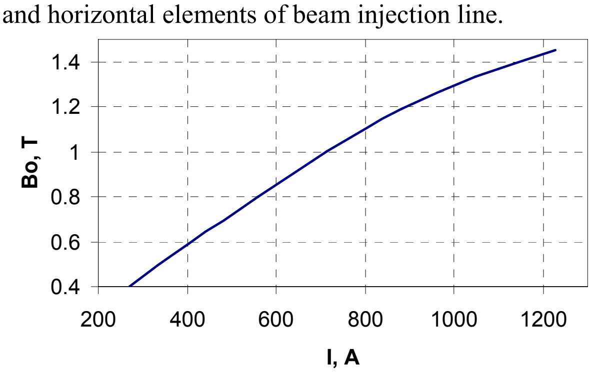

Figure 2: The current of main coil and the magnetic field level for DC-280 magnetic system.

The distance in 500-mm between poles was chosen to place the high–voltage (up to 130kV) RF system and the independent Flat-Top system. The isochronous form of the magnetic field is formed by 4 pairs of sectors. The

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sectors has no spirality and equipped with removable edge shims, placed on the both sides of each sector. The shims has the form of straight plates with 10-mm wide and are intended for final formation of the magnetic field.

THE STEEL MAGNETIC PROPERTIES

At the first stage of the magnetic field calculations the test steel magnetic properties from the program database were used. As soon as the real steel magnetic properties were measured, it was used in the final calculations. Wherein the average magnetic field decreases at 29±4 Gs for 0.64T, 81±3 Gs for 1.05T and 89±9 Gs for 1.32T.

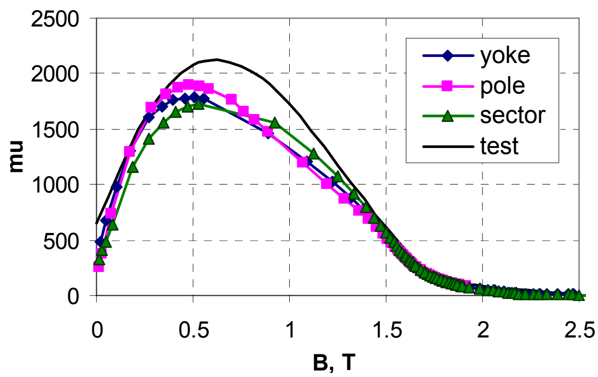

Figure 3: The test and real steel magnetic properties.

THE CORRECTING COILS

To form the isochronous accelerating modes, presented by the working diagram, the DC-280 cyclotron has eleven radial correcting coils. The radial coils are placed between pole and sectors, figure 1. The maximum power consumption of all eleven coils with the current 25A is no more then 2×8kW. Each coil has 2×78 turns. It is enough to produce the required sum contribution of the radial coils about ±1000Gs to form the accelerating modes of the DC-280 cyclotron. 3[th] and 10[th] trim coils have a separate power supplies for upper and lower sub coils and could be used for correction of the beam vertical position. At the figure 4 the contributions of DC-280 trim coils with 25A current supply is presented.

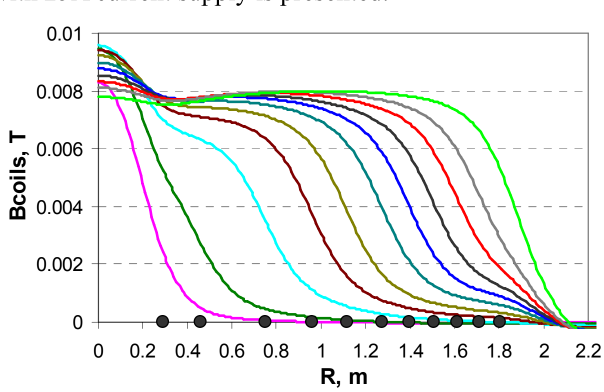

Figure 4: The contributions of the radial coils at the average magnetic field level 1.32T.

Four pairs of azimuhal coils are intended for correction of first harmonic of magnetic field and for adjust beam orbit centring. Azimuthal coils are placed on the sectors at the side of working area, figure 1. One pair of azimuthal coils can create up to 0.0025T of amplitude of the first harmonic, figure 5. Two pairs of azimuhal coils are placed perpendicular one to another in two rows at radiuses:

- R=1.5m, coils are intended for common correction;
- R=1.78m, coils are intended to correct the beam position before extraction.

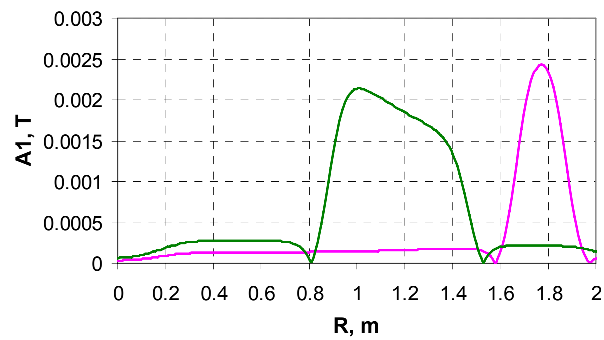

Figure 5: The amplitude of the first harmonic, created by one pair of azimuhal coil.

MAGNETIC FIELD AT CENTRE REGION

Because DC-280 cyclotron magnetic field is varied in a wide range of levels, 0.64 – 1.32T, the magnetic structure is saturated unevenly. It leads to a non uniform changing of magnetic field for different levels. Especially it is dramatic at the central region [2,3].

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

- formation of the isochronous field
- minimization of non uniform changing of magnetic field for different levels.

For DC-280 cyclotron both problems were solved by finding the special form of central region elements: sector noses, centre plugs and shims.

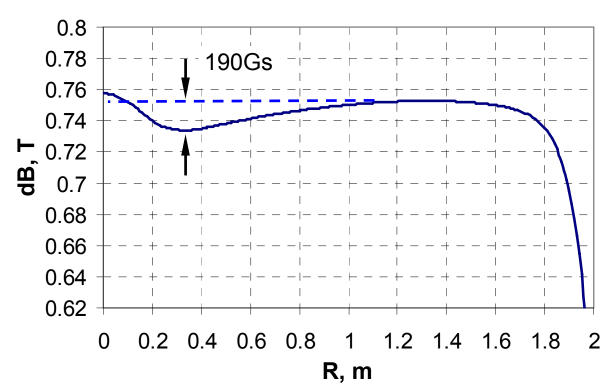

Figure 6: The difference between the average magnetic fields at the high, 1.32T and low, 0.64T levels.

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The form of the difference between the average magnetic fields at the high, 1.32T and low, 0.64T levels was taken as a criteria of the magnetic field formation. In ideal case this difference at the centre must be a flat form. For DC-280 the best difference was found about 190Gs, figure 6. The payment for this was some difference of the formed magnetic field from isochronous, figure 7. This difference can be partially compensated by trim coils. At figure 7 the example of formation of 48Ca8+ acceleration mode by trim coils is presented. The "calculated" field presents the "iron" formed magnetic field, and "formed" field is a result of trim coil usage. As a result, the phase shifting of accelerated beam at the "formed" magnetic field is not more then $\pm 3^o$.

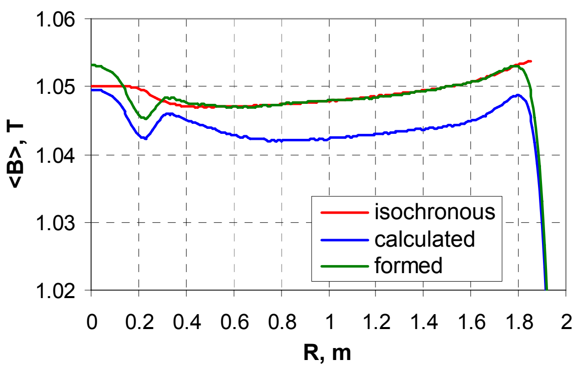

Figure 7: The isochronous, calculated and formed with trim coils magnetic field for 48Ca8+ acceleration mode.

MAGNETIC CHANNEL INSTALLATION

DC-280 extraction system is equipped with the passive magnetic channel, placed at the extraction radius in the vertical gap between pair of sectors, figure 8.

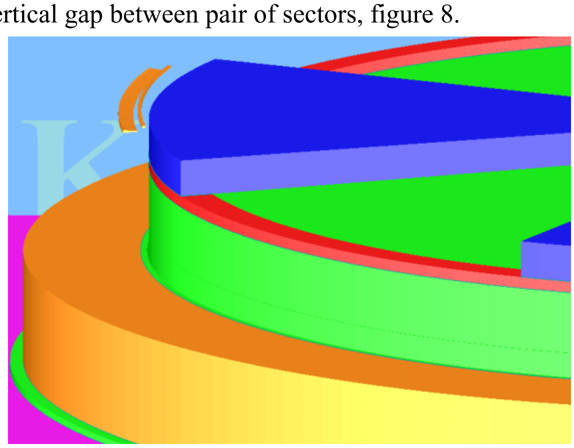

Figure 8: The passive magnetic channel installation at the computer model of DC-280 magnet.

The calculation of the magnetic field with the passive magnetic channel was carried out on the computer model with 1/2 geometry of the cyclotron magnet (360^o on the azimuth). At the figure 9 the perturbation of the magnetic field after channel installation is shown. The calculations has shown, that up to the extraction radius 1.78m, the average magnetic field is changed not more than 2Gs from initial form and the amplitude of induced first harmonic less than 4Gs. The compensation of the passive magnetic channel influence will be held during magnetic field measurements by means of the sector shims [4].

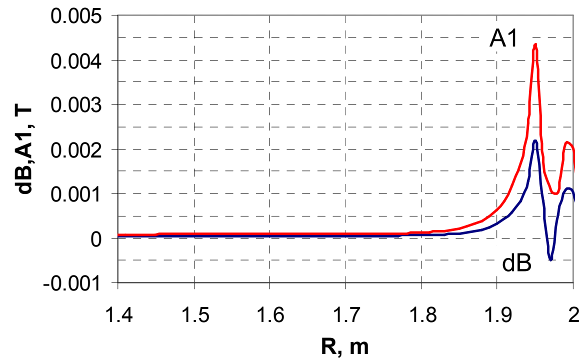

Figure 9: The average magnetic field perturbation and first harmonic amplitude after magnetic channel installation.

PRESENT STATUS

At present time the magnet is manufactured and wait for transportation to Dubna, figure 10.

Figure 10: DC-280 magnet at the manufacture.

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