MAGNETS OF INJECTION AND EXTRACTION SYSTEMS OF CYCLOTRON DC280

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Abstract

The design of two magnets of the cyclotron DC280 is presented. The magnets are the parts of injection and extraction systems the cyclotron. The design is based on three-dimensional calculation of the magnet field carried out by using OPERA 3D program code. The influence of the magnetic fields nonlinearities on ion beam dynamics is analyzed.

INTRODUCTION

The isochronous heavy-ion cyclotron DC-280 is a basic part of the Super Heavy Element Facility – the new accelerator complex of Joint Institute for Nuclear Research [1]. The DC-280 cyclotron will produce high-intensity beam of accelerated ions in the range from helium to uranium. The maximum design value of a current of ion beams will be 10 pmcA and the maximum kinetic energy will be 8 MeV/u.

In this report the design of two magnets IM90 and TM50 of SHEF is presented. The analyzing magnet IM90 is a part of high voltage injection system of DC-280 cyclotron [2]. The switching magnet TM50 is placed in extraction beam lines [3] of the facility. Depending on the magnitude of the magnetic field in magnet, the particles move on five orbits corresponding to different bending angles (0, ±25 and ±50 degrees) of the ion beam. The design is based on three-dimensional calculation of the magnet field carried out by using OPERA 3D program code [4]. The 3D computational models of the magnets are shown in Fig.1.

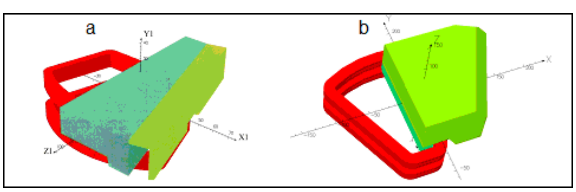

Figure 1: 3D models of IM90 (a) and TM50 (b) magnets

The 3D macro-particle beam dynamic simulation in the magnets was done in the curvilinear coordinates system connected with reference orbit, defined for computational field map. This simulation was carried out by using MCIB04 program code [5].

Inhomogeneities of the magnetic field distribution in the vicinity of the reference orbit were evaluated by Fourier analysis of the magnetic field map.

The optimum value of the basic geometrical characteristics of the magnets influencing on the form of the field distribution are found.

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REFERENCE ORBITS OF THE MAGNETS

The reference orbits of the magnets are shown in Fig.2,3. In the case of IM90 magnet the initial approximation for the angular width of the magnet pole (84.75 degrees) found by using the results of [6] gave a good agreement of the effective bending radius (497.4 mm) and it design value (500 mm).

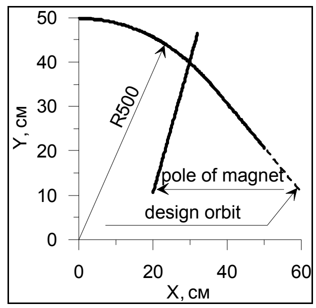

Figure 2: Reference orbit of IM90 magnet

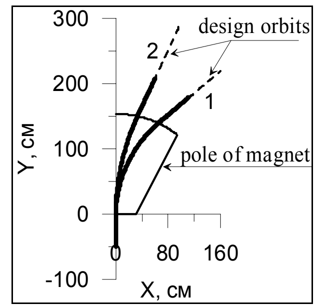

Figure 3: Reference orbits of TM50 magnet

The magnetic fields distributions at reference orbits are shown in Fig. 4-6.

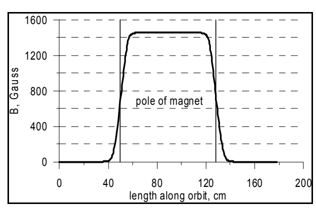

Figure 4: Bz field along reference orbit of IM90 magnet

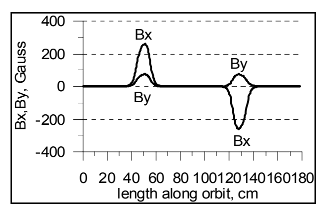

Figure 5: Bx,y field at 2 cm higher reference orbit of IM90 magnet

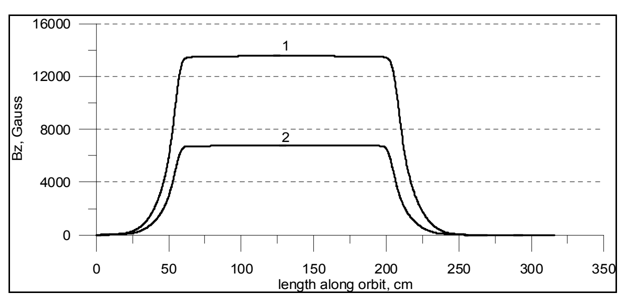

Figure 6: Bz field along reference orbits of TM50 magnet

MAGNETIC FIELD INHOMOGENEITIES

Inhomogeneities of the magnetic field distribution in the vicinity of the reference orbit were evaluated by Fourier analysis of the magnetic field map:

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$$B_z = B_0 \sum_{n=0}^{\infty} b_n(r,s) r^n Cos(n\varphi) \qquad (1)$$

Here (r,φ) is a polar coordinates of point in the curvilinear system connected with reference orbit, B_0 is the value of magnetic field in the midpoint of trajectory.

Dependence of the amplitudes of the first $b_1(r,s)$ and second $b_2(r,s)$ harmonics on the length along the orbit s at different radii r for the magnet IM90 is shown in Fig.7,8.

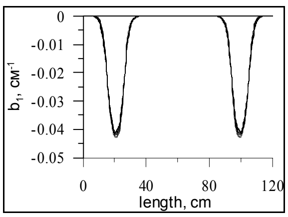

Figure 7: Quadrupole $b_1(r,s)$ component of magnetic field of IM90 magnet

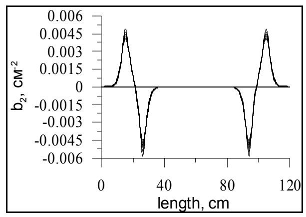

Figure 8: Sextupole $b_2(r,s)$ component of magnetic field of IM90 magnet

The same dependencies for the magnet TM50 are shown in Fig.9-12.

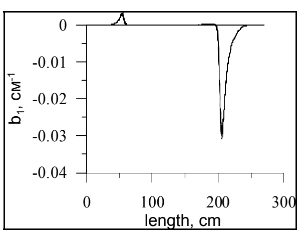

Figure 9: Quadrupole $b_1(r,s)$ component of magnetic field of TM50 magnet. Orbits 1,5

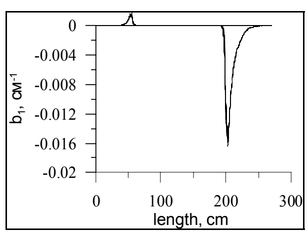

Figure 10: Quadrupole $b_1(r,s)$ component of magnetic field of TM50 magnet. Orbits 2,4

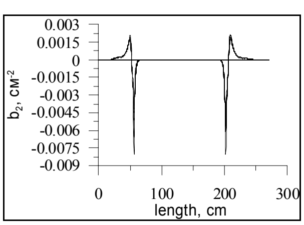

Figure 11: Sextupole $b_2(r,s)$ component of magnetic field of TM50 magnet. Orbits1,5

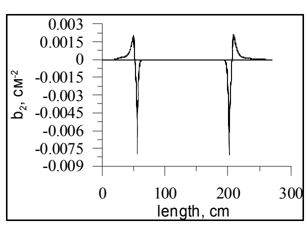

Figure 12: Sextupole $b_2(r,s)$ component of magnetic field of TM50 magnet. Orbits2,4

BASIC CHARACTERISTICS OF MAGNETS

In the case of IM90 magnet the optimum value of the basic geometrical characteristics influencing on the form of the field distribution are found. Selected geometric pole edge angle of the magnet (26.0 degrees) ensures symmetry of focusing on both transverse coordinates. The optimum value of the distance from the pole boundary to the magnetic screen (70 mm) reduces the effect of sextupole nonlinearity to an acceptable level. The growth of RMS emittance of the beam due to sextupole nonlinearity is not greater than 12.5%. The plots of the beam envelopes and emittance are shown in Fig.13,14.

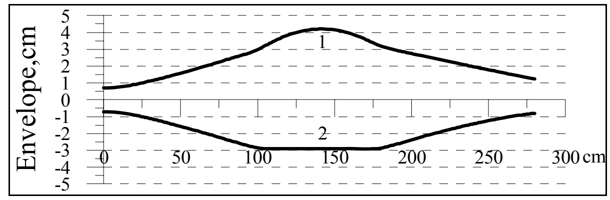

Figure 13: Envelopes of the ion beam for horizontal (1) and vertical (2) motion

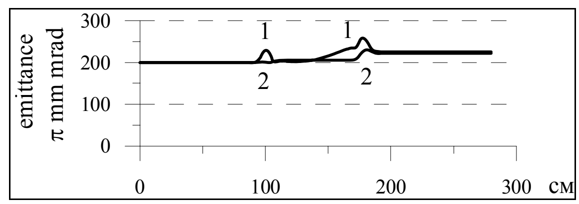

Figure 14: Emittances of the ion beam for horizontal (1) and vertical (2) motion

Particle distributions in the various phase planes at the image point of the IM90 magnet are shown in Fig.15.

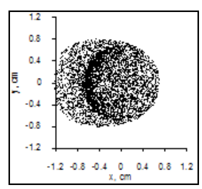
Figure 15a: Plane (x,y)

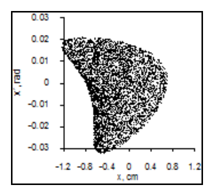
Figure 15b: Plane (x,x′)

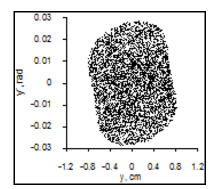
Figure 15c: Plane (y,y′)

Using of the focusing solenoid installed at the entrance of the magnet significantly reduces the effect of sextupole nonlinearity on the dynamics of particles. In this case the growth of RMS emittance is not greater than 2.8%.

In the case of TM50 magnet the actual bending angle θ for the orbit does not coincide with the design value φ. This is explained by a violation of symmetry of vertical magnetic field with respect to the mid-point of trajectory. The parameters of the orbits in TM50 magnet are contained in Table 1.

Table 1. Orbits parameters

Orbit number	Design bending angle φ, degree	Actual/ design bending radius, mm	Actual/ design exit edge angle, degree	$\|\theta-\varphi\|$, mrad
1,5	± 50	1887/1823	20.5/25	0.443
2,4	± 25	3699/3560	11.5/12.5	0.365

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The envelopes of the ion beam transported through TM50 magnet are shown in Fig.16,17.

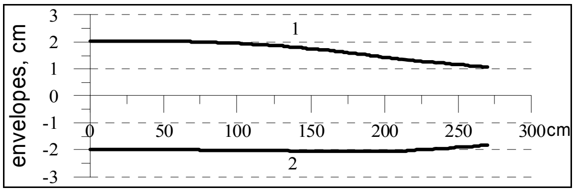

Figure 16: Horizontal (1) and vertical (2) beam envelopes at orbits 1,5

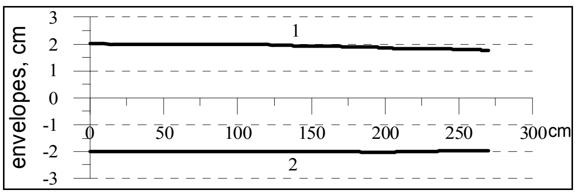

Figure 17: Horizontal (1) and vertical (2) beam envelopes at orbits 2,4

The emittances of the beam are shown in Fig.18,19.

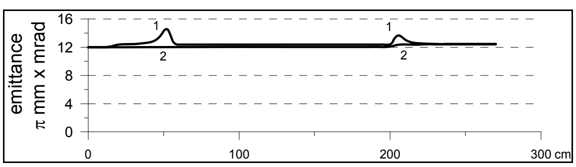

Figure 18: Horizontal (1) and vertical (2) beam emittances at orbits 1,5

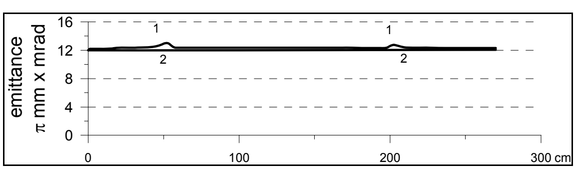

Figure 19: Horizontal (1) and vertical (2) beam emittances at orbits 2,4

RMS emittance of ion beam is increased by 3.4% for orbits 1,5 and 2.6% for orbits 2,4 due to sextupole nonlinearity of magnetic field.

CONCLUSION

Simulation of the dynamics of ion beams in the injection [2] and extraction [3] beam lines by means of the calculated three-dimensional maps of the magnetic field has shown the possibility of using the magnets IM90 and TM50 while creating the corresponding channels.

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