SCREENING OF CYCLOTRON MAGNETIC FIELD IN C400 AXIAL INJECTION BEAM-LINE

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Abstract

The screening of the optical elements placed at the horizontal part of the axial injection beam-line of the C400 cyclotron for hadron therapy is performed. An influence of the injection channel shielding elements on magnetic field distribution in the median plane of the C400 cyclotron was studied. The 3D ANSYS model is used for this purpose.

INTRODUCTION

The C400 cyclotron for carbon therapy is developing by IBA in collaboration with JINR. The axial injection channel of the cyclotron (Fig.1) includes four ECR ion sources, two bending magnets (BMR40 and BMR20 with bending radii of 40 and 20 cm correspondingly) and four quadrupoles [1].

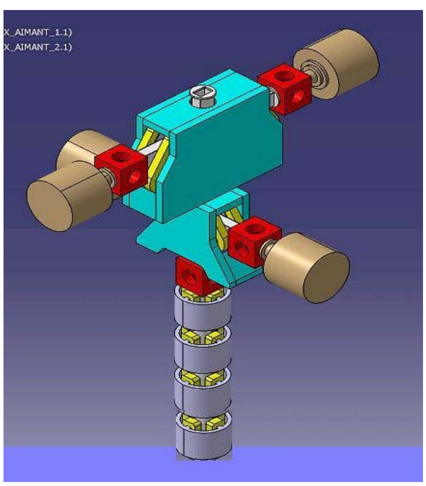

Figure 1: View of C400 axial injection channel.

The C400 cyclotron magnetic field in the bending magnets region has values of 700 – 1000 G. Big value of this field affects significantly the particles trajectories and leads to necessity of shielding the horizontal parts of the injection channel as well as the bending magnets. As it was shown in [2] the transverse magnetic field in the channel must be less than 10 – 15 G to avoid the significant particle losses in the inflector. Besides the shielding of the channel must conserves the functionality of the bending magnets the quadrupole system and the C400 cyclotron.

For these purposes simulations were performed by means of POISSON (2D case) and ANSYS (3D case) programs. Corresponding models of the C400 cyclotron and the injection channel were created. It should be noted that these models don't reproduce C400 design exactly.

SCREENING OF REGION OF BENDING MAGNETS AND HORIZONTAL PARTS OF BEAM-LINE

The following shielding elements were proposed to reduce the magnetic field in the region of bending magnets and horizontal parts of beam line (Fig.2 – Fig.3) up to acceptable values. The thickness of lateral walls of bending magnets is increased from 5 cm up to 15 cm. The clearance between the magnets is filled by a steel insertion. A hole inside this insertion is a rectangle with sides of 25 and 20 cm. An insertion down stream BMR20 shields a part of vertical channel with length 27 cm. A hole of this element is a square with a side of 20 cm. Additional insertions are used for shielding of horizontal channels from ECR ion sources to bending magnets BMR40 and BMR20. These insertions have rectangular holes with the dimensions 33 × 20 cm and 24 × 20 cm correspondingly. Top walls of insertions shielding horizontal beam lines to bottom magnet BMR20 have a thickness of 15 cm. All insertions provide holes as well as diagnostic boxes. Shielding insertions around ECR ion sources are also used in ANSYS model. The mass of the shielding elements excluding the original magnets is about 5.4 tons.

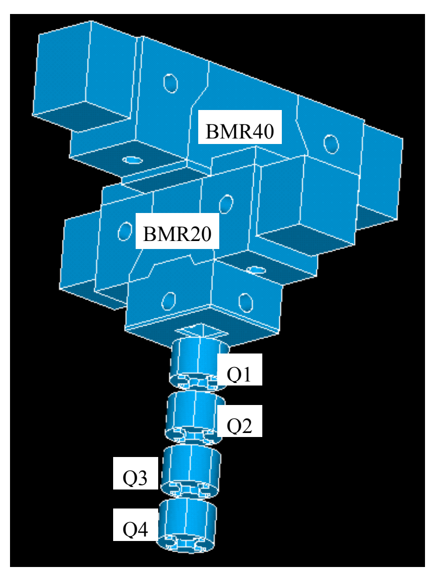

Figure 2: Overall view of screened injection channel.

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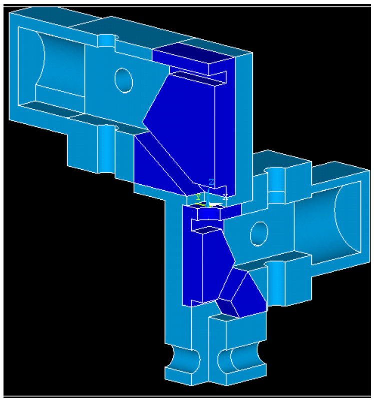

Figure 3: Section of screening elements.

Proposed shielding permits to reduce the C400 magnetic field just in whole the region of bending magnets and horizontal channels up to value less than 10 G except the edges of bends where the field can reach of about 20 G.

INFLUENCE OF SCREENING ON MAGNETIC FIELD OF BENDING MAGNETS

The screening of the injection channel results in increasing the level of magnetic fields of the bends on 10 – 20 G. Such small change of the level (≤ 2%) inside the bending magnets can be compensated by reduction of current in coils.

The magnetic field distribution along beam reference trajectory is presented in Fig. 4. A path from ECR ion source through BMR40 to quadrupoles is taken as a beam trajectory.

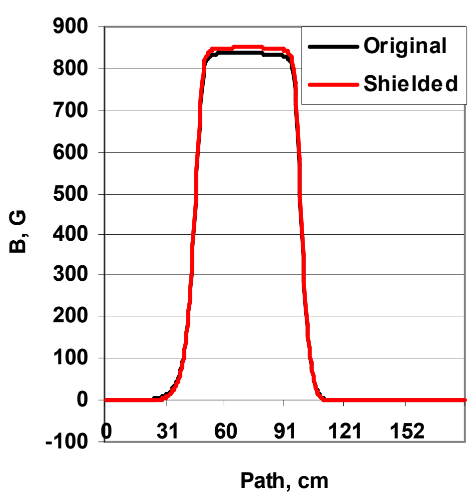

Figure 4: Magnetic field distribution along reference trajectory of beam motion.

INFLUENCE OF SCREENING ON MAGNETIC FIELD IN REGION OF QUADRUPOLE SYSTEM

As simulations have shown the influence of the screening elements on the C400 magnetic field in the region of quadrupoles is insignificant. The magnetic field in this region can be presented as azimutally symmetric. In this case the radial component of the field can be expressed as $B_\rho = -\frac{\rho}{2}\frac{\partial B_z}{\partial z}$. The influence of such radial magnetic field on beam optics in quads may be reduced by its rotating [1].

INFLUENCE OF SCREENING ON MAGNETIC FIELD IN MEDIAN PLANE OF C400 CYCLOTRON

2D and 3D simulations have been performed for investigation of an influence of screening elements on the magnetic field distribution in the C400 median plane. Differences of the magnetic field values in cases of the screening elements presence and their absence were considered.

The simulations have shown that the screening elements presence influences on the field distribution in the following way. The median plane is shifted towards the screening elements and at the same time absolute values of the magnetic field are increased. This effect leads to an appearance of a radial component of the magnetic field in the median plane. A sign of the radial component depends on a direction of the magnetic field flow through the median plane and the location of the screening elements relative to the median plane. If the flow are directed towards the shield then the radial component has negative values, otherwise it has positive values.

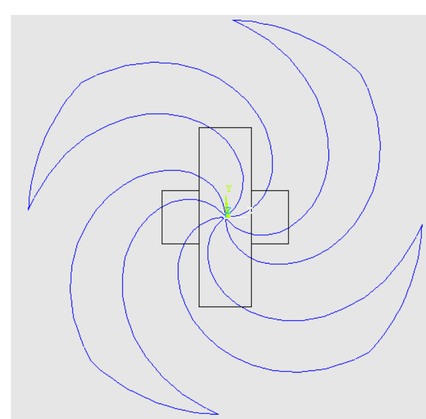

Figure 5: Location of sectors and screening elements.

3D model has permitted to investigate a change of the magnetic field distribution in azimuth direction in contrast to 2D simulation. In 2D model the screening elements were approximated by a cylinder while in reality they have a cross-shaped form. Crossbars of the shield have different lengths and are located on different distances from the median plane. A location of the C400 sectors and the shield relative to each other (see Fig. 5) can also influence on how the magnetic field distribution in the median plane are changed due to the screening.

Radial component of the magnetic field in the presence of the screening elements is negative and its average absolute value increases with radii up to 10 – 12 G. Moreover the radial component in the C400 valleys has greater absolute values than between sectors. Azimuthal component of the field is less significantly and does not exceed 1 G just in whole the median plane. Axial component values increase on about 14 – 15 G. In contrast to the radial component it possesses greater values between sectors of the cyclotron. Dependence of average absolute values changing on radii is presented in Fig. 6.

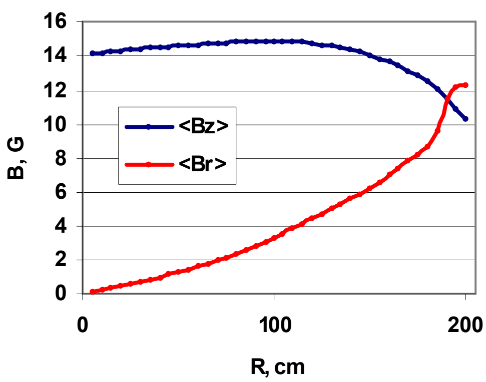

Figure 6: Dependence of average absolute values of axial and radial components on radii

Spectral analysis of the axial and radial components has shown that harmonics divisible by 4 are most significant ones for both components. Amplitudes of other harmonics are far less. Dependences of amplitudes of 4^{th}, 8^{th} and 12^{th} harmonics are presented in Fig.7 – Fig.8.

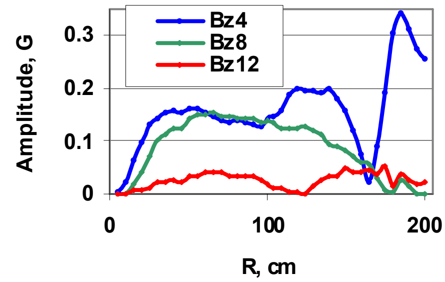

Figure 7: Dependence of amplitudes of harmonics of axial component on radii.

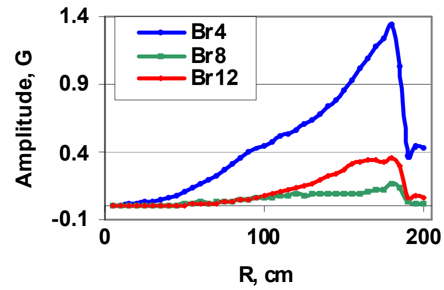

Figure 8: Dependence of amplitudes of harmonics of radial component on radii.

The magnetic field distributions in planes parallel to the median one differ from the distribution in the median plane on values less than 1 G. Thus it can be concluded that the change of the C400 magnetic field in the region of beam dynamics due to the screening elements presence does not depend significantly on axial coordinate.

REFERENCES

[1] N. Kazarinov, V. Aleksandrov, Y. Jongen, V. Shevtsov, "Axial injection beam-line of C400 cyclotron for hadron therapy," these proceedings.

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