SIMULATION OF EXTRACTION MAGNETIC ELEMENTS FOR C400 SUPERCONDUCTING CYCLOTRON

Y. Jongen, M.Abs, W.Beeckman, A.Blondin, W. Kleeven, D.Vandeplassche, S.Zaremba, IBA, Louvain-la-Neuve, Belgium, G. Karamysheva, N. Morozov, S. Kostromin, E. Samsonov, JINR, Dubna, Russia

Abstract

The superconducting cyclotron (C400) is under design at IBA (Belgium) [1, 2]. The cyclotron will be able to accelerate $12C^{+6}$ and $2H^{+}$ ions up to the energy 400 MeV/nucleon and protons with the energy close to 260 MeV. The basic technical design line for the cyclotron extraction system uses passive magnetic correctors. By computer simulation with the 2D (POISSON) and 3D (TOSCA, MERMAID and MAFCOD) codes the principal design parameters of the extraction magnetic elements were estimated and their magnetic field maps were simulated. The field maps obtained are used for dynamic simulation of the extracted beam.

INTRODUCTION

The cyclotron has a compact-type superconducting magnet [2] with a pole of radius 187 cm. The basic layout and specifications of the extraction elements were determined by numerical analysis of the extraction trajectories [3]. The possibilities of extraction of carbon ions by means of electrostatic deflector (E=140 kV/cm) and protons by means of 2H+ ion stripping as well as precise alignment of these beams at ~3 m from the cyclotron just in front of the energy degrader were studied. The plan view of the carbon ion extraction trajectory and extraction channel is shown in Fig.1. Table 1 shows the specifications of the extraction elements.

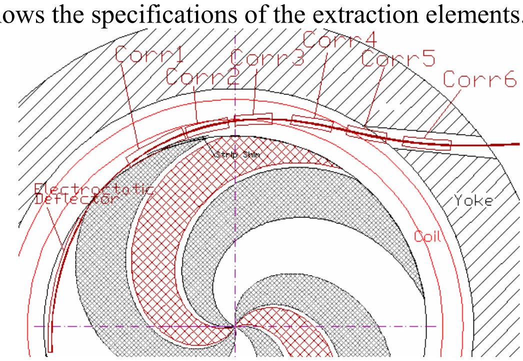

Figure 1: Schematic layout of the extraction elements and carbon ion trajectory

Table 1: Specification of the extraction elements

Element	φ_1°	φ_2°	Aperture (mm)	E (kV/cm)	dB/dx (T/m)
Deflector	262	305	3	140	-
Corrector 1	327	345	20	-	4
Corrector 2	346	359	15	-	20
Corrector 3,4	360	370	20	-	±22
Corrector 5	375	399	25	-	-6
Corrector 6	402	410	25	-	12

The basic idea in the extraction magnetic channel design was to use passive iron correctors. This choice was made after studying the magnetic field of the electromagnetic quadrupole in a strong external field. The simulation of this configuration demonstrated that the quadrupole magnet lost its effectiveness and created a strong unwanted magnetic field perturbation. A three bars design was used for each corrector. The choice of the corrector bar geometry was provided by the MAFCOD code [7] which can simulate the magnetic field from the system of uniformly magnetized iron bars. As the C400 magnetic correctors are in a rather high external magnetic field, this assumption is to be right. This assumption was proved by 3D model simulations. The assumption of the uniform magnetization was proved for the external fields not less then 1 T. For the lower level of the external magnetic field the 3D models were used.

CORRECTOR 1

Corrector 1 was designed by minimizing the volume of iron as its influence on the magnetic field perturbation at the cyclotron beam acceleration region is maximal. The cross-section of the corrector iron bars and its magnetic field and gradient are shown in Fig.2. The magnetic field perturbation in the cyclotron working region is shown in Fig.3. The corrector magnetic field map was simulated by the MAFCOD code. For crosschecking of the simulation accuracy the TOSCA code [5] was used. Figure 4 shows the TOSCA model of the cyclotron magnetic system near the sector edge region with the corrector iron plate. The results of magnetic field simulations for the corrector plate by the MAFCOD and TOSCA code are presented in Fig.5.

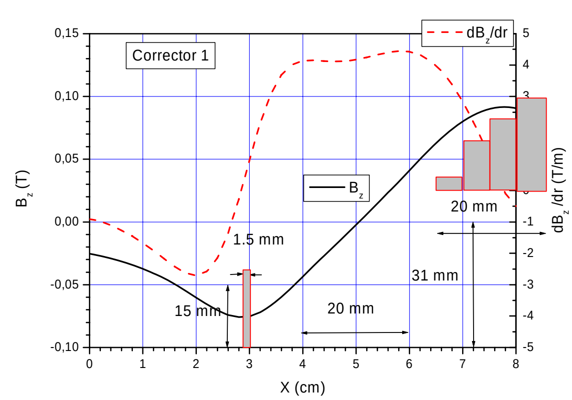

Figure 2: Transverse dependence of the magnetic field response for corrector 1

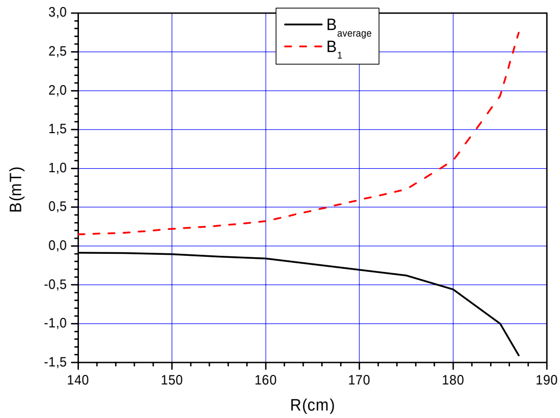

Figure 3: Perturbation of the magnetic field for the working region of the cyclotron

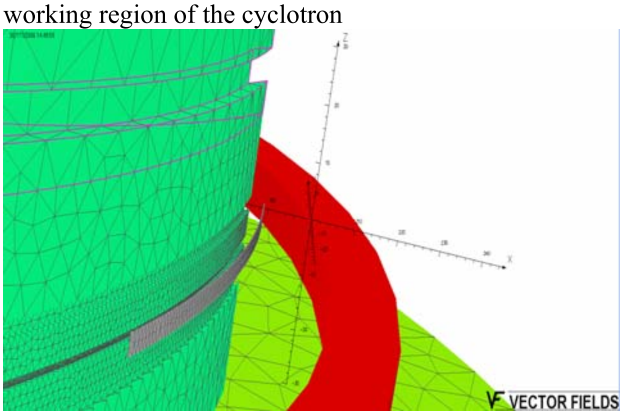

Figure 4: TOSCA model with the corrector plate

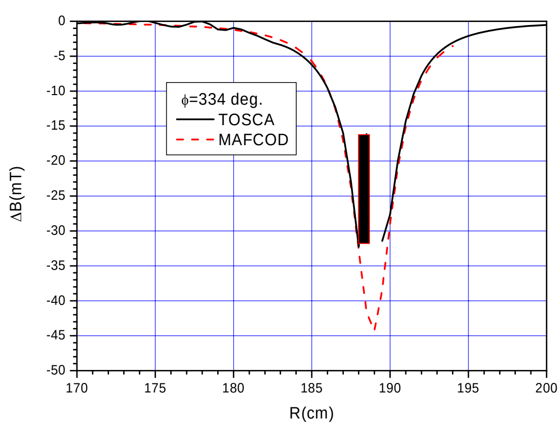

Figure 5: Magnetic field response for the corrector plate, φ=334º

CORRECTORS 2-4

Correctors 2, 3 and 4 have approximately the same parameters and are installed in a rather high cyclotron fringe magnetic field (1.2-2 T). These correctors have the same design. The cross-section of corrector 4 iron bars and the corrector magnetic field is shown in Fig.6. As the end part of corrector 4 is in the fringe field ~1.2 T, the checking of this field magnetization ability for corrector 4 was realized by a 2D POISSON model (Fig.7). The effect of the magnetization field in this model was provided by the current coil. The magnetic field gradient for corrector 4 weakly depends (Fig.8) on the external field level (2 – 1.2 T).

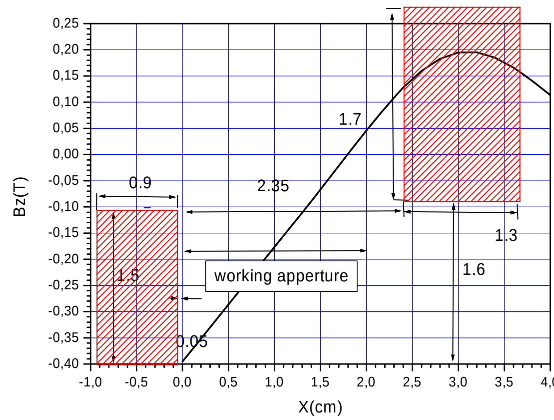

Figure 6: Transverse dependence of the magnetic field response for corrector 4

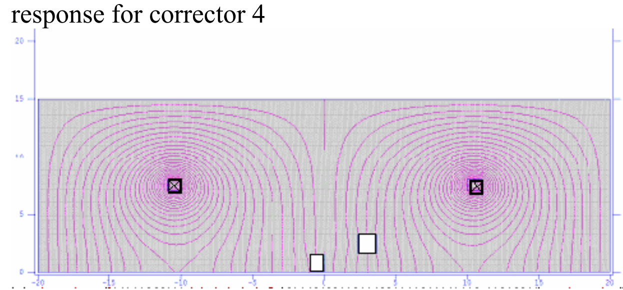

Figure 7: 2D POISSON model for corrector 4

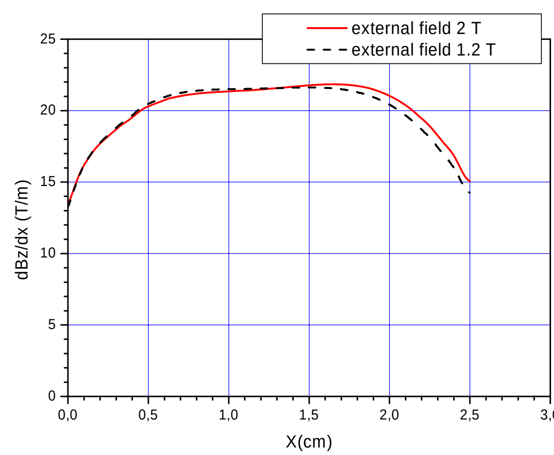

Figure 8: Magnetic field gradient for corrector 4 due to different level of the external magnetic field

CORRECTORS 5-6

Corrector 5 is placed in the fringe magnetic field which is changing linearly in the range ±1.2 T. As the part of the corrector is in a very low external field, the 3D MERMAID code [6] was used. In the test MERMAID model (Fig.9) a piece of conductor was used for the external magnetic field generation. The results of the magnetic field simulation for corrector 5 are presented in Fig.10-11.

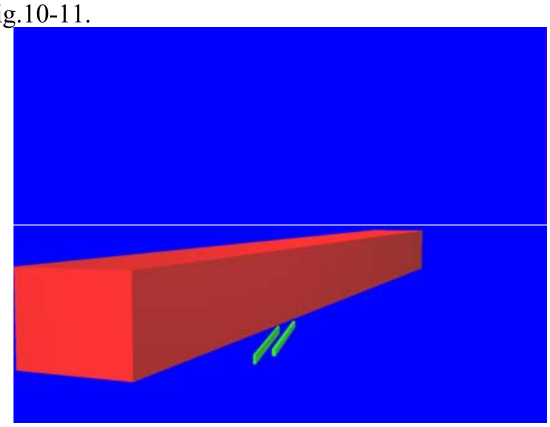

Figure 9: MERMAID code model for the corrector 5 test (3D view)

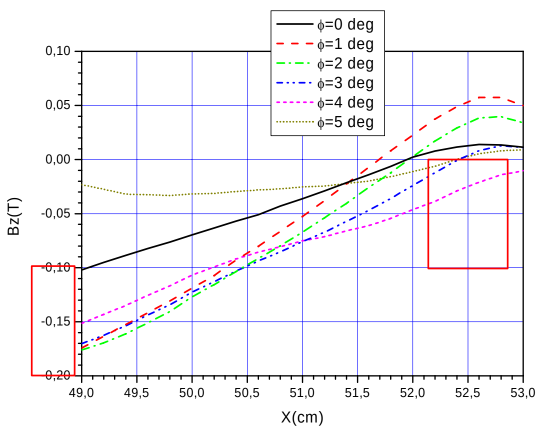

Figure 10: Transverse dependence of the magnetic field response for corrector 5 at different azimuth angles

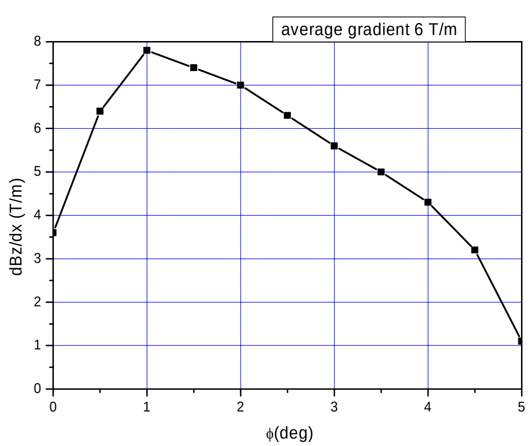

Figure 11: Central magnetic field gradient along corrector 5 (½ length)

The corrector 6 design and magnetic field simulation were done with the MAGCOD and MERMAID code. The cross-section of the corrector iron bars and the corrector magnetic field and gradient are shown in Fig.12 and 13.

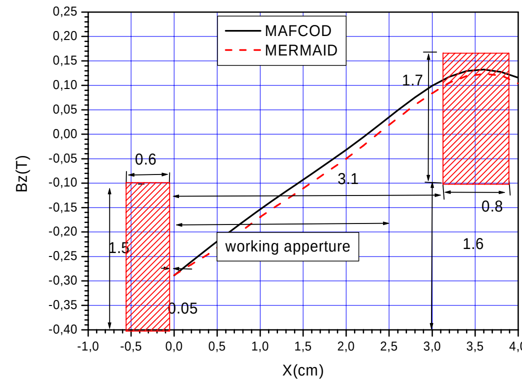

Figure 12: Transverse dependence of the magnetic field response for corrector 6

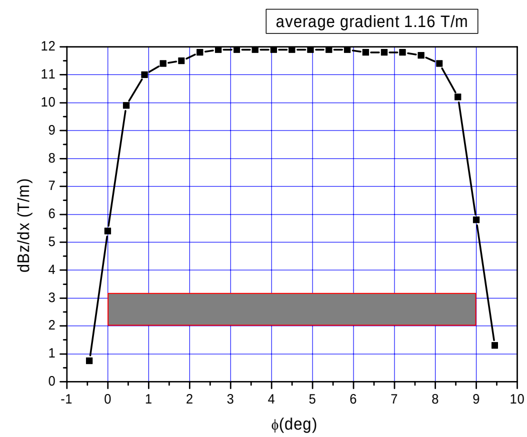

Figure 13: Central magnetic field gradient along corrector 5

REFERENCES

[1] Y.Jongen et al., "Design Studies of the Compact Superconducting Cyclotron for Hadron Therapy", EPAC'06, Edinburgh, UK 26-30 June 2006, TUPLS078.

[2] Y.Jongen et al., "IBA C400 Cyclotron Project for Hadron Therapy", this conference.

[3] Y.Jongen et al., "Simulation of Two Beams Extraction from Superconducting Cyclotron C400", this conference.

[4] POISSON/SUPERFISH User's Guide, LA-UR-87-115, Los Alamos Accelerator Code Group.

[5] OPERA 2D and 3D, Vector Fields, UK, www.vectorfields.com.

[6] MERMAID, User's Guide, SIM Limited, 2005.

[7] MAFCOD, User's Guide, LNP internal report, Dubna, 1980.