MAGNETIC SYSTEM FOR SC200 SUPERCONDUCTING CYCLOTRON FOR PROTON THERAPY

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Abstract

The superconducting cyclotron SC200 for proton therapy that is under design by ASIPP (Hefei, China) and JINR (Dubna, Russia) will be able to accelerate protons to the energy 200 MeV with the maximum beam current of 1 μA. A conceptual design study with 3D codes for the superconducting cyclotron magnet has been carried out during 2015-16 at ASIPP and JINR. The main design considerations are reviewed. The results obtained by numerical field computation for a suitable choice of design parameters are presented. Results of numerical calculations are the basis for technical design of SC200 cyclotron.

CYCLOTRON OVERVIEW AND ITS PARAMETERS

In order to respond to the increasing interest in Russia and China for proton therapy, JINR and ASIPP have started the development of a dedicated proton therapy facility in frame of the China-Russia joint research center on superconducting protons accelerator. The center has been founded in Hefei, east China's Anhui province recently. The research center, co-built by the Joint Institute for Nuclear Research of Russia and Institute of Plasma Physics of Chinese Academy of Sciences, aims at developing SC200 - China's first compact superconducting cyclotron for medical application - within three years. SC200 will be used for accurate treatment of cancer. The systems and components related to SC200 is expected to be manufactured by the Institute of Plasma Physics by 2017 and both parties will jointly assemble these systems and components and complete the whole project by 2018.

The main SC200 cyclotron design characteristics:

- Compact design similar to the lot existing cyclotrons
- Fixed energy, fixed field and fixed RF frequency
- Bending limit W=200 MeV
- Accelerated particles: protons
- Superconducting coils enclosed in cryostat, all other parts are warm
- Injection by PIG ion source
- Extraction with an electrostatic deflector and passive magnetic channels

MAGNETIC SYSTEM SIMULATION

The preliminary choice of the magnetic system parameters was provided by 2D codes (POISSON [1] and OPERA-2D [2]). At this stage the basic magnet system sizes and sectors gap parameters were estimated. The optimization of the spiral sectors parameters and final choice for magnet design has been done by TOSCA, the magneto-static module of OPERA-3D, 3D code ANSOFT MAXWELL [3] and CST code [4].

At the each step of the magnet optimization the simulated magnetic field maps were analysed by the beam dynamic codes and the beam extraction procedure was studied too.

The SC200 cyclotron model view is shown in Fig. 1. The magnetic field map calculated in the median plane of the cyclotron is shown in Fig. 2.

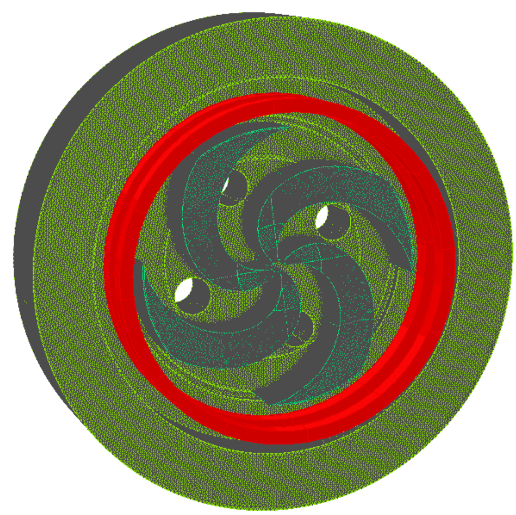

Figure 1: Layout of the TOSCA model for SC200 cyclotron.

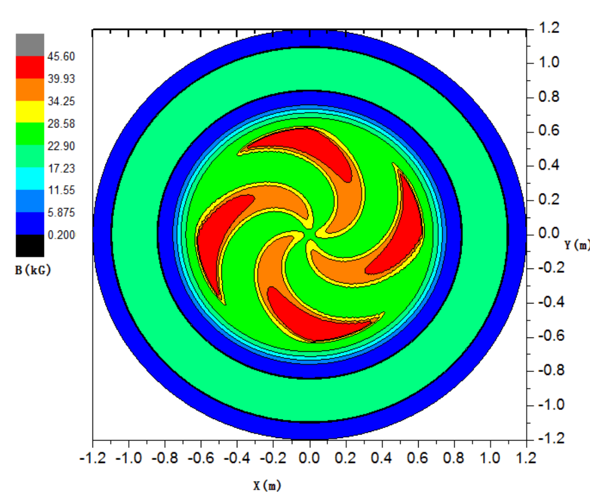

Figure 2: Contour plot of median plane magnetic field.

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The average magnetic field shaping was realized by:

- Magnet pole profiling (additional valleys sectors are used),
- Sectors gap profiling at the final radii,
- Small profiling of the sectors azimuth width,
- Tuning of the vertical and radial position of the magnet main excitation coils.

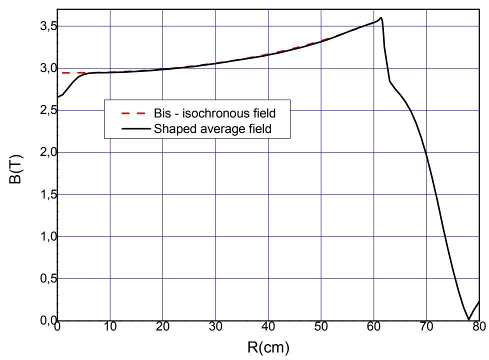

Figure 3: Average magnetic field.

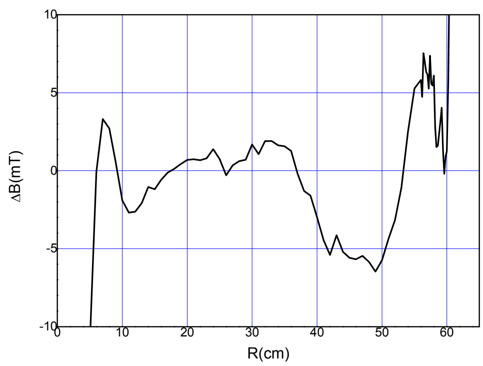

Figure 4: Accuracy of the required average magnetic field shaping.

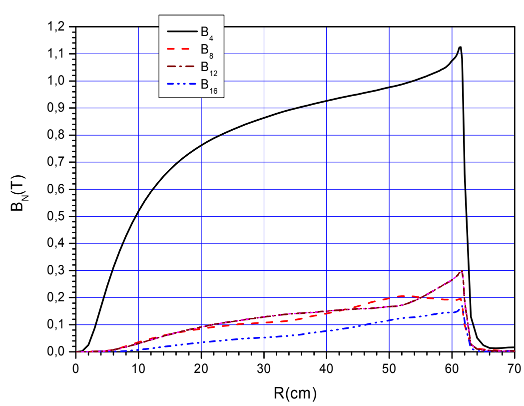

Figure 5: Multiple Fourier harmonics of cyclotron magnetic field.

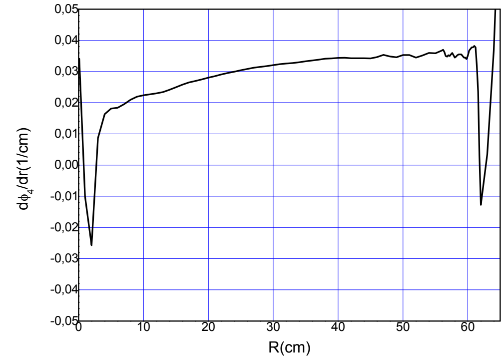

Figure 6: Derivative of the fourth harmonic phase.

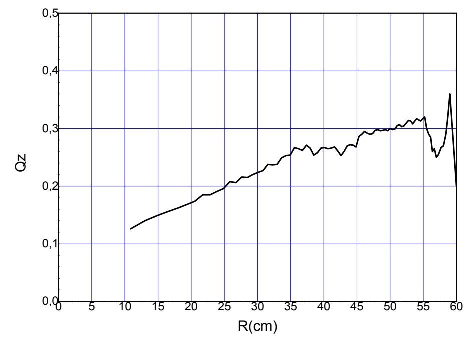

Figure 7: Vertical betatron frequency for the isochronous cyclotron magnetic field.

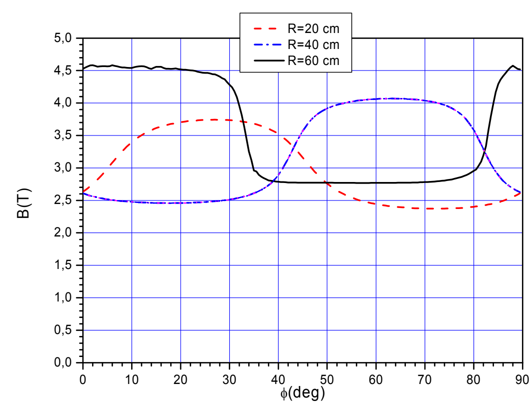

Figure 8: SC200 magnetic field for R=20, 40, 60 cm.

The shaped average magnetic field is shown in Fig. 3. The final deviation of the average magnetic field from isochronous one (Fig. 4) was achieved in range ± (5-6) mT. The basic number Fourier harmonics are shown in Fig. 5 and the fourth harmonic phase derivative in Fig. 6. The optimized sectors geometry provides vertical tune Qz~ 0.3, near the cyclotron extraction region Qz was shaped as close as possible to 0.35 (Fig. 7). Such law of Qz leads to smaller vertical beam size and to not so hard tolerance condition for the magnetic field horizontal components in the median plane of the cyclotron. The azimuth magnetic field distribution for three cyclotron

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radii R=20, 40 and 60 cm is shown in Fig.8. The main parameters of the magnet are shown in Table 1.

Table 1: Main Parameters of the Magnet SC200

Parameters	**Value**
Average field (central/extraction)	2.9/3.6 T
Hill/valley field	2.8/4.6 T
Number of sectors	4
Sector angle	40 deg
Maximum spirality	65 deg
Sector gap (max/min)	40/5 mm
Valley gap (max/min)	600/530 mm
Pole diameter	1.24 m
Dimension (diameter/height)	2.2/1.22 m
Ampere*turns (1 coil)	750 000
Weight	30 t

MAGNET, COILS AND CRYOSTAT

The preliminary design of SC coils and cryostat is shown in Fig. 9. The magnetic field simulation has resulted in providing the preliminary cyclotron design (Fig. 10).

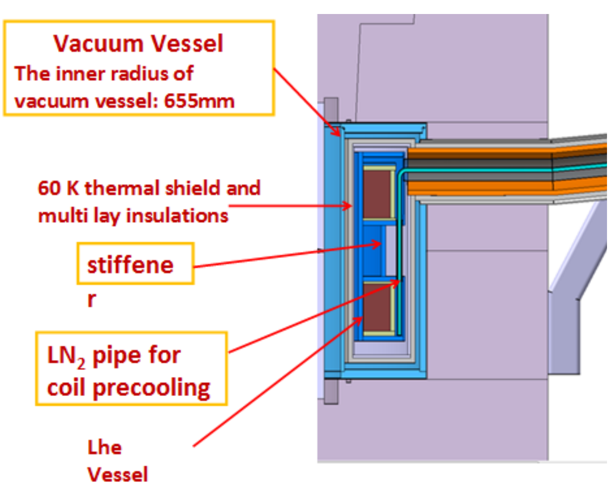

Figure 9: Preliminary design sketch of the cryostat.

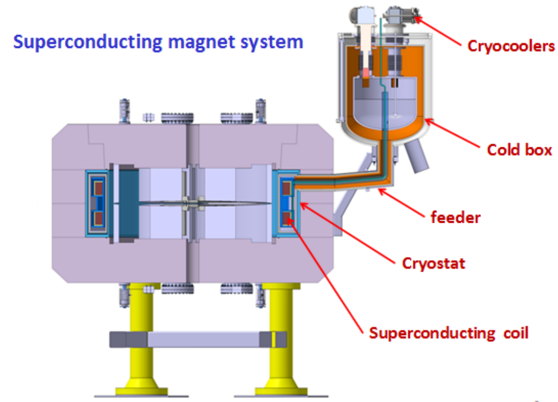

Figure 10: SC200 cyclotron magnet preliminary design.

CONCLUSION

The computer modelling by the 3D codes of the magnet system for SC200 superconducting cyclotron has been performed. The fine optimization of the magnet yoke and spiral sectors parameters has been realized in the cyclotron compact design. The computer models have provided the field maps which allowed to verify by beam dynamic simulation the feasibility of a superconducting proton cyclotron with energy 200 MeV. The technical design of the cyclotron should be realized to the end of 2016.

REFERENCES

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

[2] OPERA 2D and 3D, Software for Electromagnetic Design, www.cobham.com/technicalservices .

[3] MAXWELL 3D, www.ansoft-corporation.software .

[4] CST code, www.cst.com

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