COMPACT SUPERCONDUCTING CYCLOTRON SC200 FOR PROTON THERAPY

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Abstract

The SC200 superconducting cyclotron for hadron therapy is under development by collaboration of ASIPP (Hefei, China) and JINR (Dubna, Russia). Superconducting cyclotron SC200 will provide acceleration of protons up to 200 MeV with maximum beam current of 1 μA in 2017-2018. We plan to manufacture in China two cyclotrons: one will operate in Hefei cyclotron medical center the other will replace Phasotron in Medico-technical center JINR Dubna and will be used for cancer therapy by protons. Now we present results of simulation of magnetic, accelerating and extraction systems. The cyclotron is very compact and light, the estimate total weight is about 35 tons and extraction radius is 60 cm. We have performed simulations of all systems of the SC200 cyclotron and specified the main parameters of the accelerator. Average magnetic field of the cyclotron is up to 3.5 T and the particle revolution frequency is about 45 MHz, these parameters increases the requirements for the accuracy of all simulations.

INTRODUCTION

The Medico-technical complex (MTC) JINR annually treated at the proton beam more than 100 people. For treatment MTC uses proton beam with energy up to 200 MeV specializing mainly on treatment of head localizations.

The 200 MeV final energy has been chosen for SC200 cyclotron based on the experience of work of the MTC JINR and statistics for necessary depth of treatment provided by HIMAC (Japan) concerning the treated patients from 1995 to 2001 [1].

The proton beam with energy 200 MeV can irradiate all of the tumor localizations with a maximum depth of 25 cm. SC200 cyclotron will also be used for eye melanoma treatment at energies 60-70 MeV after degrading beam energy. Degrading the 200 MeV energy to 60-70 MeV would provide better beam quality compared to degrading from conventional energy 250 MeV.

Taking into account the fact, that the size and cost of the cyclotron are approximately determined by the maximum proton energy, it was decided to limit the maximum proton energy to 200 MeV.

SC200 is an isochronous superconducting compact cyclotron. Superconducting coils will be enclosed in cryostat, all other parts are warm. Internal ion source of PIG type will be used. It is a fixed field, fixed RF frequency and fixed 200 MeV extracted energy proton cyclotron. Extraction will be organized with an electrostatic deflector and magnetic channels. For proton acceleration we are planning to use 2 accelerating RF cavities, operating on the 2nd harmonic mode.

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MAGNET SYSTEM OF CYCLOTRON SC-200

The design of the SC200 magnetic system is described in details in [2]. Most accurate results of simulations were received in the parametrized model of the magnet (see Fig. 1) created in CST studio. Change of parameters automatically changes computer model. In addition, sector geometry can be replaced by importing from Matlab. Results of simulations are exporting to Matlab for analyzing by conventional CYCLOPS-like code or for particle acceleration in 3D fields. So we had powerful model to change quickly a number of parameters of the magnet in order to receive isochronous field with suitable betatron frequencies.

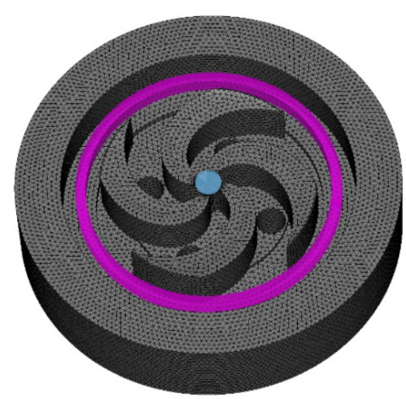

Figure 1: 3D meshed model of the magnet, central “plug” (steel cylinder connecting the sectors) is 4cm in diameter.

Isochronism of the average field was reached by decreasing of the sector width correspondently to orbital frequencies in closed orbits. Initially azimuth width of sector was equal 40 degrees. Azimuthal width of sector against radius which provide isochronous field is shown in Fig. 2. Maximal cut of the sector width will reach 18 mm. Orbital frequencies of the final average field (Fig. 3) are presented in Fig. 4. From Fig. 4 we can estimate that difference between mean field and isochronous is about 1-2 G in accelerating region. We would like to notice that all results were received with not very big number of mesh cells about 4 millions.

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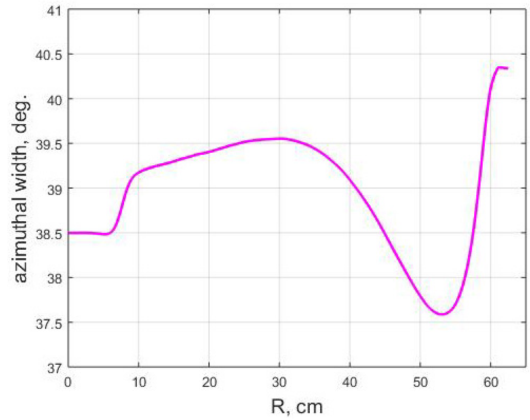

Figure 2: Azimuthal width of sector.

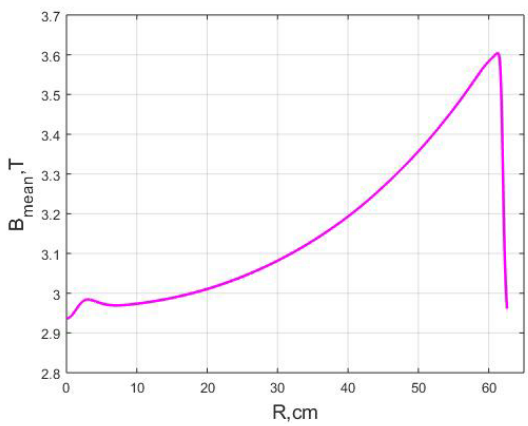

Figure 3: Average magnetic field along the radius.

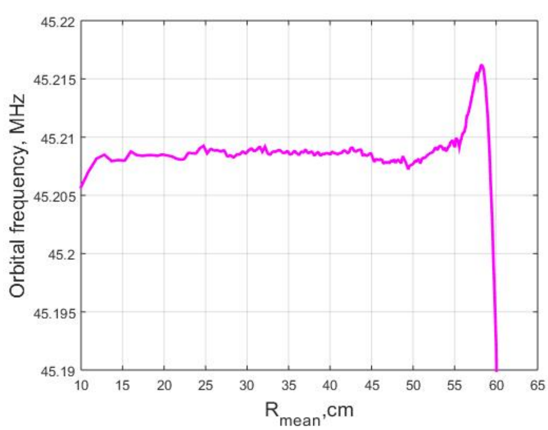

Figure 4: Orbital frequency against mean radius.

CYCLOPS-like code was used to calculate the betatron tunes. Betatron tunes are presented in Fig. 5.

As we are going to use just 2 RF cavities operating on 2nd harmonic mode, each 50 degrees in azimuthal length, the acceleration is going to be relatively week on each turn. So avoiding resonances is crucial for the design of the SC200 cyclotron.

Many efforts have been done to avoid the most dangerous resonances during acceleration 2Qz=1 and Qr-Qz=1. One can see that the first resonance is avoided completely while the second one is close at the end of acceleration. We are going to continue as well our efforts to avoid this resonance by changing magnet parameters at edge region while real shaping of the magnetic field.

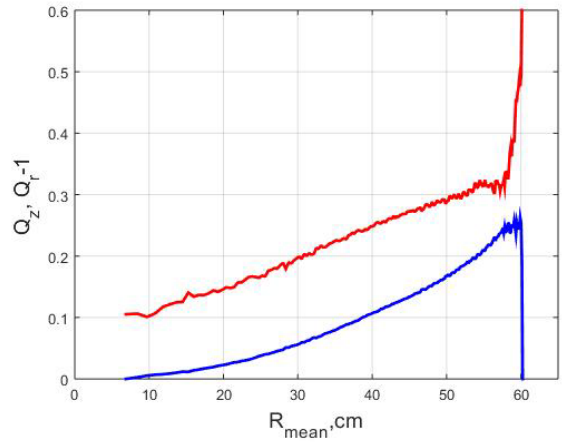

Figure 5: Vertical and radial betatron tunes in SC200.

RF SYSTEM

Two RF cavities, connected in the centre will be working on the 2nd harmonic on approximately 90MHz.

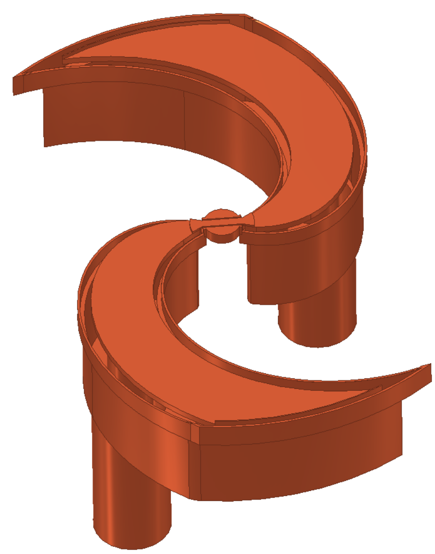

Figure 6: Overview of 3D model of RF system.

From the beam dynamics point of view the choice of 2nd harmonic is not the best solution, as the acceleration rate will be lower compared to 4th harmonic which seems like a natural choice for a cyclotron with 4 sector structure.

However, operating on 180 MHz would raise problems with the extraction of particles from the ion source and the generators on 180 MHz are not widely available as compared to 90 MHz ones. As we avoid all critical resonances and extraction scheme does not require high acceleration rate we are able to use just 2 cavities on the

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2nd harmonic. Computer simulations of the cavity was performed (see model in Fig. 6) Suitable accelerating frequency and voltage along radius (Fig. 7) were achieved. Accelerating system is described more detailed in report [3] of this conference.

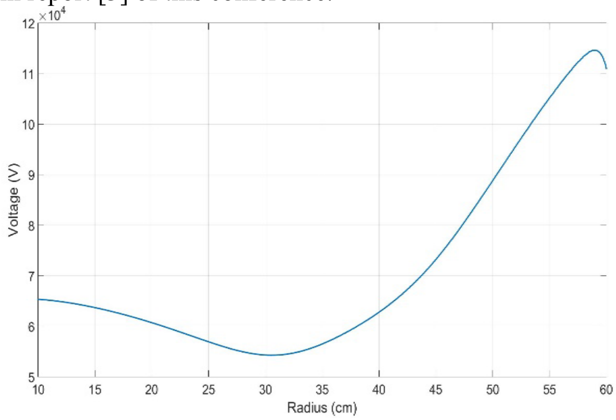

Figure 7: Mean acceleration voltage along radius.

CENTRAL REGION STUDIES

Internal PIG proton source will be used in our cyclotron, so our simulations start from the inside of the source. We have built a 3D model of the source and the central region. In order to increase the efficiency of the extraction of the protons from the source the first accelerating gap between the tip of the RF dee and the source should be kept as small as possible. However, sparking must be prevented, so we need to provide safe distance in both vertical and horizontal directions. The compact size of the accelerator is the major challenge in the design of the central region. The cylinder, connecting the sectors in the central region has to be as small as possible in diameter, so the magnetic field variation can start at the smaller radius to help with the vertical focusing, but also has to be big enough and close enough to the median plane to provide the area with the decreasing magnetic field (so-called "bump").

We have chosen to use 60 kV in the central region, and in this case the major problem was to bypass the source on the first turn. In order to do so, we had to shape the dee tips in the centre in such way to provide optimal acceleration rate.

We have used our 3D model of the RF system and the magnet in order to simulate the particle trajectories in the central region. It is clear that focusing and the energy gain using are good enough. However, it is very important to keep in mind that the final design will be strongly affected by the changes in magnet model, when we will get the measured BH curve of the steel, that will be used in the SC200 magnet.

EXTRACTION

Simulations show that the extraction can be provided by deflector with electric field 160 kV/cm and two magnetic channels MC1 and MC2 focusing the beam in horizontal plane (see Fig. 8) [4].

No need of the channel to focus the beam in vertical plane. This is provided by drop of edge magnetic field. The collimator will be used to match the beam parameters with requirements imposed by a transport system.

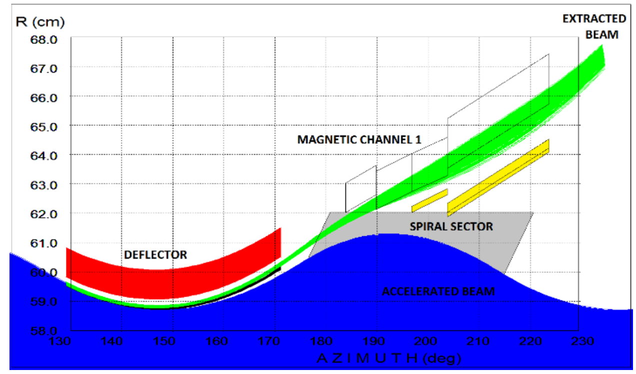

Figure 8: First part of the extraction system with deflector and MC1.

Extraction efficiency has been estimated for different changes of the septum thickness along its length and for different values of the beam radial oscillations during acceleration. Maximum attainable extraction efficiency ~75% is achieved if amplitude of radial oscillations does not exceed 2 mm and septum has constant thickness 0.1 mm.

CONCLUSION

Computer simulation of main systems of SC200 cyclotron has been performed. Simulations show that it is possible to have suitable magnetic field. Proper accelerating frequency and voltage along radius were achieved in computer simulations of the cavity. Extraction can be provided by deflector with electric field 160 kV/cm and two magnetic channels MC1 and MC2 focusing the beam in horizontal plane. The technical design of the cyclotron will be finished in 2016

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