RESEARCH AND DEVELOPMENT OF A COMPACT SUPERCONDUCTING CYCLOTRON SC200 FOR PROTON THERAPY

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Abstract

According to the agreement between the Institute of Plasma Physics (IPP) of the Chinese Academy of Sciences in Hefei (China) and Joint Institute for Nuclear Research, Dubna, (Russia), the project of a superconducting isochronous cyclotron for proton therapy SC200 is developed at JINR. The cyclotron will provide acceleration of protons up to 200 MeV with maximum beam current of 1 µA. 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 (MTC) JINR Dubna and will be used for further research and development of cancer therapy by protons. The results of testing will be used by ASIPP for a serial SC200 manufacturing. Now we present main parameters of cyclotron and first simulation results of magnetic, accelerating systems and beam dynamics.

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 upto 200 MeV specialized 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 (see Fig.1) [1].

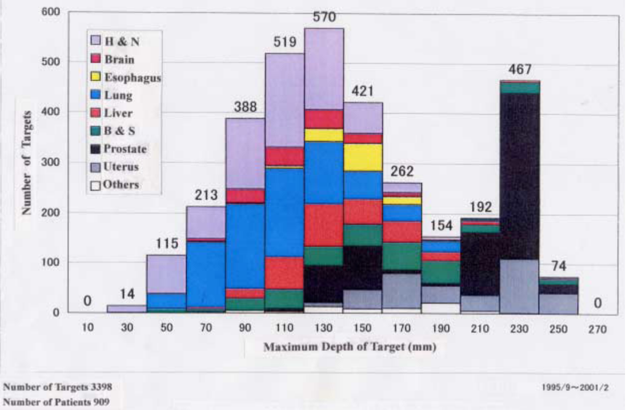

Figure 1: Distribution of maximum depths in HIMAC [1].

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.

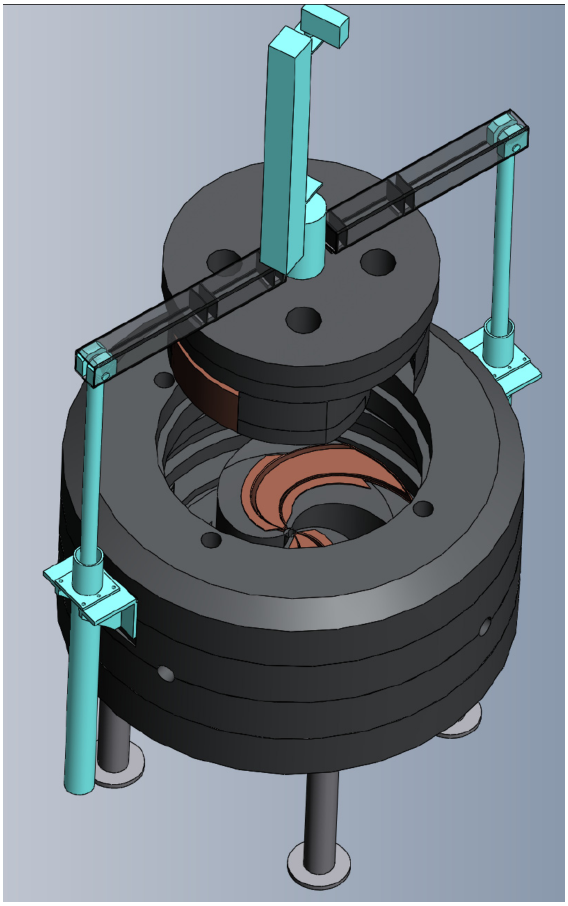

Figure 2: View of the SC200 cyclotron.

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. Mean magnetic field of the cyclotron will be in the range of 2.9T-3.5T (center-extraction). Extraction will be organized with an electrostatic deflector and magnetic channels. Currently 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 magnet modelling has been performed in 2D POISSON code, 3D ANSOFT MAXWELL and VECTOR FIELDS TOSCA software were used for optimization of the magnet design. The results of simulation of the SC200 magnetic system are described in details in [2].

The magnet's main parameters are presented in the Table 1.

Table 1: Parameters of the Magnet System of the SC200 Cyclotron

Magnet type	Compact, SC coil, warm yoke
Pole diameter (m)	1.24
Magnet diameter (m)	2.2
Magnet height (m)	1.22
Hill gap, max/min (m)	0.04-0.005
Valley gap, max/min (m)	0.6/0.53
Yoke material	St.1010
Extraction radius (m)	0.6
Average magnetic field ($R_o/R_{extr.}$) (T)	2.9/3.5
Excitation current (1 coil) (A*turns)	750 000
Magnetic field in the coil (T) max.	4.5
Cryostat and coils weight (t)	5
Total magnet weight (t)	30

Profiling of the pole shape and vertical profile of the sectors was used to shape the required isochronous magnetic field.

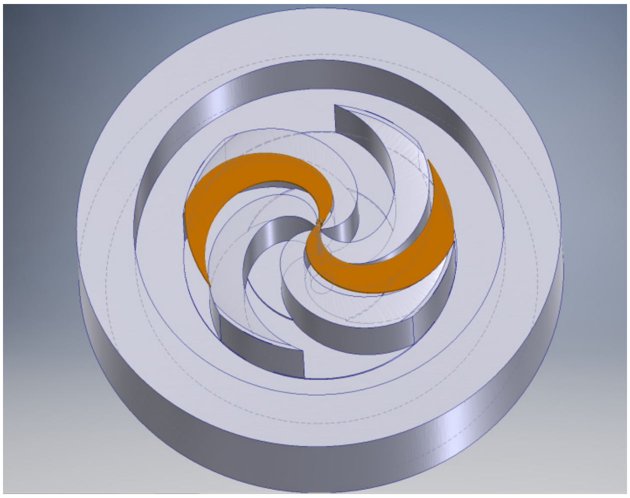

Figure 3: View of the computer model of the magnet with accelerating cavities.

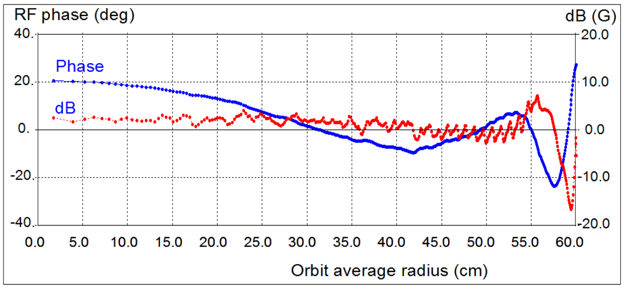

Figure 4: Deviation dB of average magnetic field from isochronous one and RF phase of the beam versus orbit average radius.

The difference between fields was calculated using a deviation of proton orbital frequency from the resonance value 45 MHz. Starting phase 20ºRF was assumed in order to provide the beam axial focusing in central region of the cyclotron.

In principle, the proton is extracted at 170 kV/cm, but trajectory seems located too long in the edge-defocusing field. Simulation of extraction for the bunch of protons is needed to define required parameters of focusing magnetic channels.

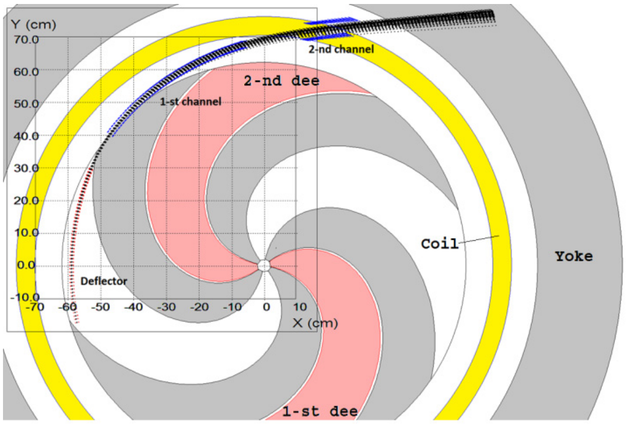

Figure 5: Scheme of the beam extraction from SC200.

3D simulations of the central region and beam dynamic simulations are presented in the report [3] at this conference.

ACCELERATION SYSTEM

Magnetic field modelling and beam dynamics have determined orbital frequency of the ions equal to about 45 MHz. To operate on 2-th harmonic, the RF system has to achieve frequency of 90 MHz. We are planning to use two normal conducting RF cavities for ion beam acceleration in the SC200 cyclotron.

The geometry of the RF cavity is restricted by the size of the valley of the magnet. We have fitted the double gap delta cavity inside the valley of the magnet. Azimuth extension of the cavity (between middles of accelerating gaps) is 50 degrees. We have chosen the accelerating gap to be equal to 7 degrees.

Main parameters of the RF system are presented in Table 2.

Table 2: Parameters of Accelerating System

RF cavities	warm
Number of cavities	2
Operating frequency, MHz	90
Harmonic number	2nd
Radial extension of the cavity, m	0.63
Radial extension of the dee, m	0.61
Number of stems	1
Diameter of the stem, m	0.09
Radial position of the stem, m	0.365

We used several software packages such as CST Microwave studio, COMSOL Multiphysics RF module and ANSYS.

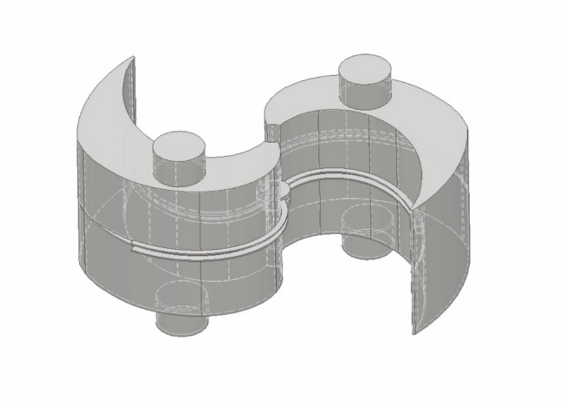

Figure 6: Computer model of the accelerating cavity.

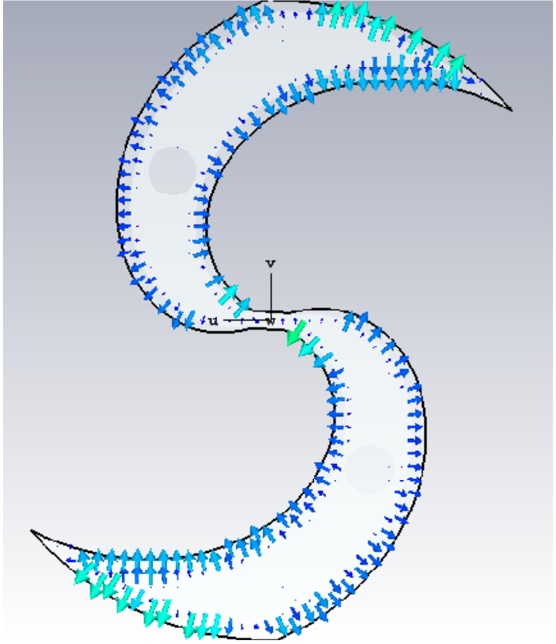

Figure 7: Vector plot of the electric field in the median plane.

Frequency of the cavity with 1 stem reaches 90 MHz with quality factor about 7500. Calculated peak losses for two cavities are equal 75 kW.

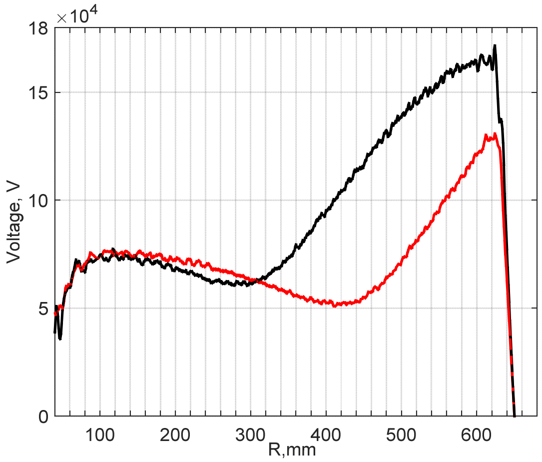

Figure 8: Voltage distribution along radius.

Voltage value along accelerating gaps was calculated by integrating of the electric field in the median plane of the resonant cavity.

However the work still has to be done to optimize parameters of the cavity.

CONCLUSION

The work on design of the proton superconducting cyclotron SC200 continues. Manufacturing of SC200 systems and elements will be done during the 2017. Assembling, tuning and testing SC200 should be finished in 2018.

REFERENCES

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[3] O.V. Karamyshev, "Beam Tracking Simulation for SC200 Superconducting Cyclotron," in *Proc. IPAC'16.*