STATUS OF THE SC202 SUPERCONDUCTING CYCLOTRON PROJECT

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Abstract

In 2015 the joint project JINR (Dubna, Russia) - ASIPP (Hefei, China) on design and construction of superconducting proton cyclotron SC202 was started. Two copies of SC202 shall be produced, according to the Collaboration Agreement between JINR and ASIPP. One will be used for proton therapy in Hefei and the second one will be used to replace the Phasotron in the research and treatment program on proton therapy at JINR. Recent status of the SC202 superconducting cyclotron for hadron therapy design and manufacture is presented.

INTRODUCTION

The design of the SC200 cyclotron was described in [1-4]. New version of cyclotron SC202 substantially differs from SC200. We increase yoke dimensions in order to decrease stray fields and decrease angular extension of sectors in order to increase a free space for accelerating system.

The 3D computer model of SC202 cyclotron view is presented in Figure 1.

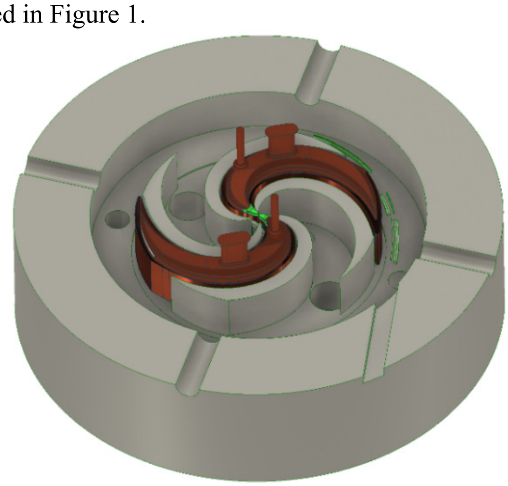

Figure 1: Layout of the cyclotron model.

MAGNET DESIGN

The SC202 magnet design was based on the main cyclotron design characteristics:

- Compact design;
- Fixed energy, fixed field and fixed RF frequency;
- Superconducting coils enclosed in cryostat, all other parts are warm;
- Injection by PIG ion source;
- Extraction with an electrostatic deflector and passive magnetic channels.
- Bending limit W=200 MeV;
- Deep-valley concept with RF cavities placed in the valleys;
- Acceleration up to ~5-7 mm from pole edge ⇒ to facilitate extraction;

Main parameters of the magnet:

- Sector angular width 22-33 degrees (from center to extraction);
- Small sectors vertical gap near beam extraction - 9mm;
- Pole radius = 61 cm;
- Outer diameter = 250 cm;
- Height = 170 cm;
- Hill field = 4.75 Tesla, valley field = 3 Tesla;
- A*turn (1 coil) 725 000;
- Weight is about 55 tons.

CST studio was used for the SC202 magnetic system design. Simulations of the SC202 cyclotron magnetic system reveal the necessity of very high accuracy especially in the extraction region. We achieve high accuracy in simulations of the magnet together with quick analysis and remodelling possibilities of all parts of model such as complex form of elliptical gap and sector profile.

Sector geometry can be replaced by importing from Matlab. Results of simulations are exported to Matlab for analysing by conventional CYCLOPS-like code or for particle acceleration in 3D fields.

Isochronism of the average field was reached by decreasing of the sector width from extraction to center region.

The sectors middle line radial dependence is presented in Fig.2.

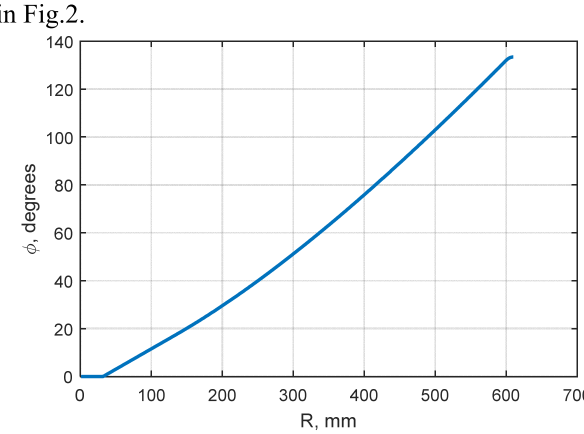

Figure 2: Angle of the middle line of the sector.

During the magnet simulations the following design goals were achieved:

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Isochronous field in whole accelerating range;
Keep last orbit close to pole edge 5-7 mm;
Keep the stray field at an acceptable level;
Avoid dangerous resonances (see Fig. 3).

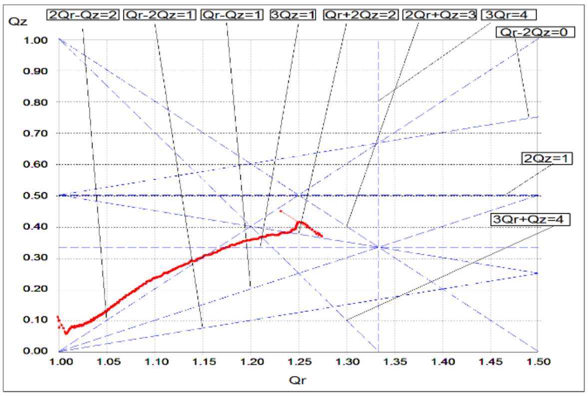

Figure 3: Tune diagram.

During the magnetic field mapping and shimming procedure, it will be possible to use the next correction elements:

- Central field shaping by changing the position and shape of the central plug.
- Magnetic field shaping by changing the azimuth width of the sectors.
- Magnetic field correction at the extraction region may be done by the sectors gap cut.

RF CAVITY DESIGN

For proton acceleration, we are planning to use 2 accelerating RF cavities, operating on the 2nd harmonic mode. The characteristic parameters of the half-wavelength coaxial resonant cavity have been accomplished based on simulation. View of the computer model of the cavity is presented in Fig. 4.

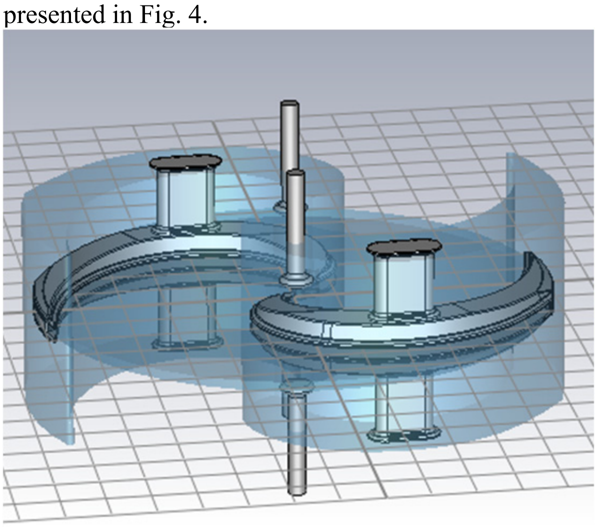

Figure 4: View of the cavity model.

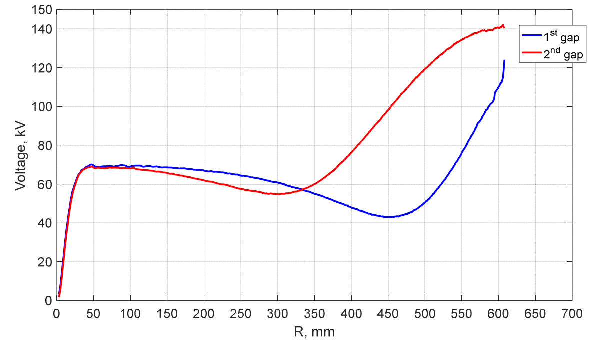

Figure 5: Voltage along radius.

Voltage in the center is about 55 kV corresponds stored energy 1 Joule in both cavities
Main results of the RF cavity simulation:
Frequency 91.7 MHz
Power losses for two RF cavities are about 93 kW. Quality factor is about 6 000.

BEAM DYNAMICS SIMULATIONS.

For all beam dynamics simulations 3D electric field maps from RF cavity simulations and 3D magnet field maps from magnet simulations were used.

Center Region.

Internal PIG proton source will be used in our cyclotron, so our simulations start from the source.

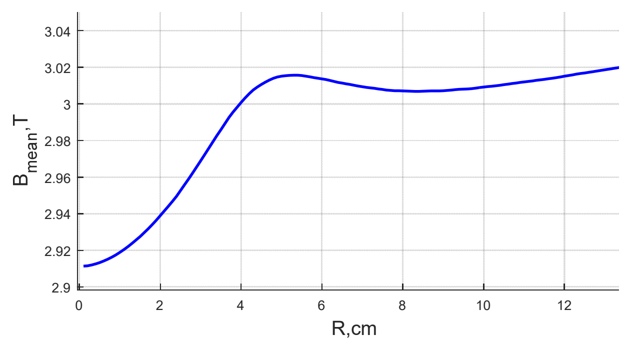

Figure 6: Average magnetic field in the center.

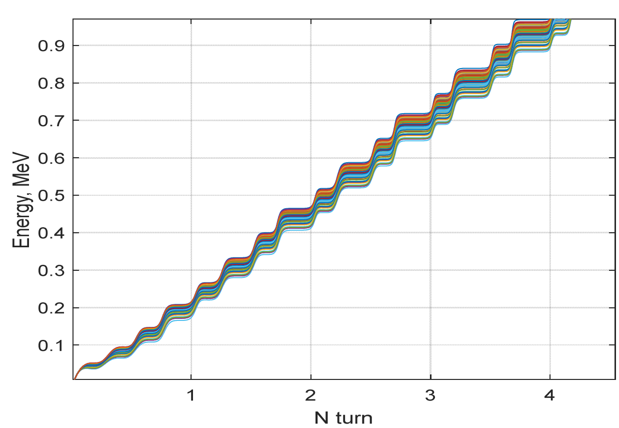

Figure 7: Energy against turn number.

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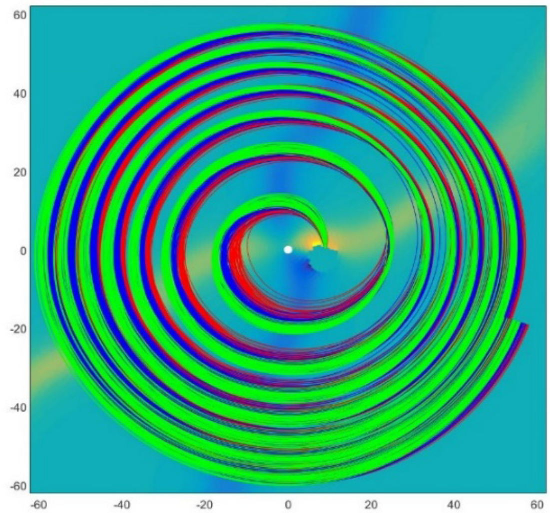

Figure 8: First turns in the cyclotron (bunch 40º RF)

Vertical focusing in the very center is provided for lagging particles by electric accelerating field for the radius up to 5 cm, after this radius magnetic focusing induced by bump occurs.

The beam has been accelerated with amplitudes of betatron oscillations up to 3 mm. There were no losses of particles in any radius after center region. There were no influence of any resonance. Acceleration was successful from ion source up to 201 MeV. It takes from about 900-1000 turns depend on field map in different models and frequency and voltage of accelerating field.

Extraction Simulation

Extraction will be organized with an electrostatic deflector and 4 magnetic channels (see Figs. 9,10). The beam is extracted applying electric field 150 kV/cm in deflector. Maximum attainable extraction efficiency ~60% is achieved if amplitude of vertical oscillations does not exceed 2 mm and septum has constant thickness 0.1 mm.

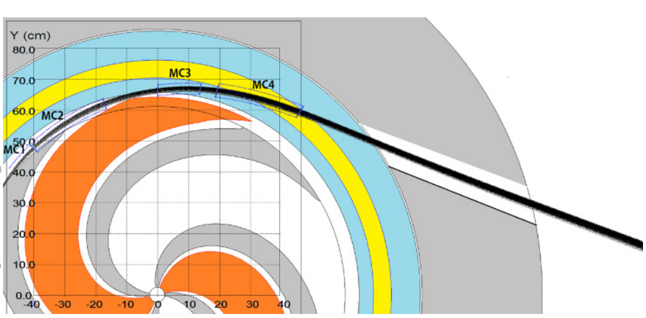

Figure 9: Extraction system on plan view .

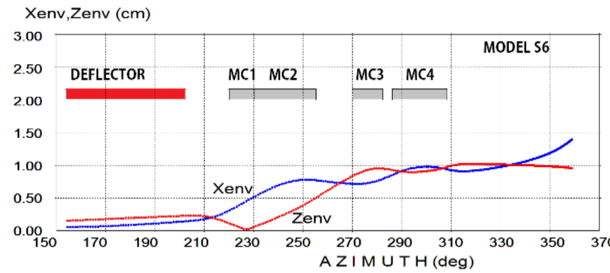

Figure 10: RMS envelopes of the extracted beam.

CONCLUSION

The engineering design of SC202 project has been completed, each subsystem is in production or experimental verification. At present, the superconducting magnet is being manufacturing, and the cryogenic electrical properties of the superconducting magnet are tested successfully, the test results meet the design requirements. The PIG ion source has been designed and assembled. The model of the RF cavity converts the RF power to the desired high frequency electric field to accelerate the particle. For the moment, the RF source and the low level control system are being processed and manufactured, and the low power test of the RF cavity is completed. The test results verify the correctness of the design, RF cavity will be manufactured in the nearest future. Design and manufacture of subsystems of SC202 are performing in accordance with the project schedule.

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