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MSC230 SUPERCONDUCTING CYCLOTRON FOR PROTON THERAPY

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Abstract

Superconducting cyclotron MSC230 is intended for acceleration of the proton beam to 230 MeV for medico-biological research. MSC230 [1,2] is an isochronous four-sector compact cyclotron with a 1.7 T magnetic field in the centre. Acceleration is performed at the fourth harmonic mode of the accelerating radio-frequency (RF) system consisting of four cavities located in the cyclotron valleys. The accelerator will use an internal Penning type source with a hot cathode. Extraction is carried out by an electrostatic deflector located in the gap between sectors and two passive magnetic channels. The current status of the project is discussed.

INTRODUCTION

Many years of practical experience in the treatment of cancer patients with proton beams at the Medical Technical Complex (MTC) of Joint Institute for Nuclear Research (JINR) [3,4] creates a unique environment for the development of innovative technologies in the field of proton therapy. Recent studies of a promising new method, called FLASH [5-7], have shown that it has great potential for expanding the use of proton therapy on tumors that previously could not be treated with protons, at the same time significantly improving the quality of treatment. The FLASH method decreases the number of irradiation procedures, and, therefore, decreases the cost of treatment, making it more affordable for an ordinary patient. The necessary equipment to study the method is available with the medical beam of the MTC DLNP, where conformal irradiation of tumors is possible. The task of the FLASH research makes relevant the creation of a research and innovation center equipped with a modern proton accelerator, a beam delivery system and laboratory equipment for biomedical research.

Table 1: Parameters of the Cyclotron

Accelerated particles	protons
Magnet type	Compact, SC coil, warm yoke
Number of sectors	4
Number of RF cavities	4
Harmonic number Frequency, MHz	4 106.5
Ion source	Internal, PIG
Final energy, MeV	230
Number of turns	500

This article is devoted to the project of a cyclotron aimed at obtaining an intense proton beam. In the coming years, it is planned to create a cyclotron and equipment for studying the FLASH-irradiation method. Main parameters of MSC230 cyclotron are presented in Table 1. Computer model of the cyclotron is seen in Fig. 1.

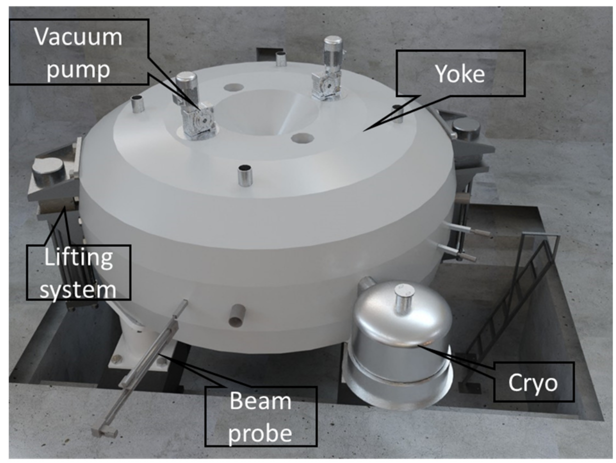

Figure 1: View of the cyclotron's 3D computer model.

MAGNET SYSTEM

The MSC230 magnet is composed of a superconducting (SC) solenoid and an iron yoke. The technology with the use of a hollow composite SC cable, proposed at JINR and well-proven in the magnets of the Nuclotron synchrotron, was chosen as the basis for the manufacture of the solenoid. JINR has a base for the production of such a cable, which requires only the modernization of the existing equipment.

To achieve high intensity of the beam it is necessary to provide an intense source of ions and minimize losses at all stages of acceleration. It is easier to ensure a high transmission coefficient in a cyclotron with a lower magnetic field, so we chose the value of the magnetic field in the centre equal to 1.7 T. Simulations of the magnet and accelerating systems were performed in CST studio [8] (see Fig. 2).

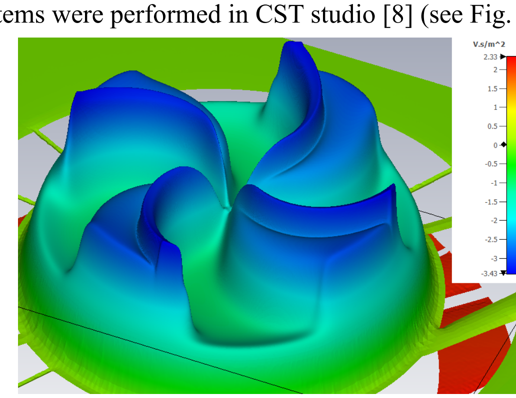

Figure 2: Magnetic field distribution.

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Average magnetic field and flutter along the radius are presented in Fig. 3.

Code CORD (Closed ORbit Dynamics) code [9] was developed during the design of SC200 [10] and MSC230 cyclotrons. Code gives necessary information about the possibility of particle acceleration by analysis of closed equilibrium orbits in calculated electromagnetic fields. For the correct formation of the magnetic field in an isochronous cyclotron, it is necessary to ensure the same frequency of rotation of particles in closed equilibrium orbits for the entire range of radii and stability of radial and vertical motion. Also, the course of the working point on the tune diagram, should not intersect dangerous resonances. Calculated betatron frequencies are presented in Fig. 4.

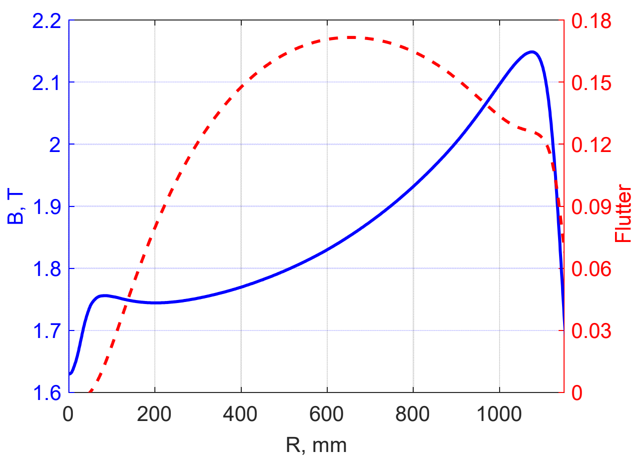

Figure 3: Average magnetic field (blue solid line) and flutter (red dashed line) along the radius.

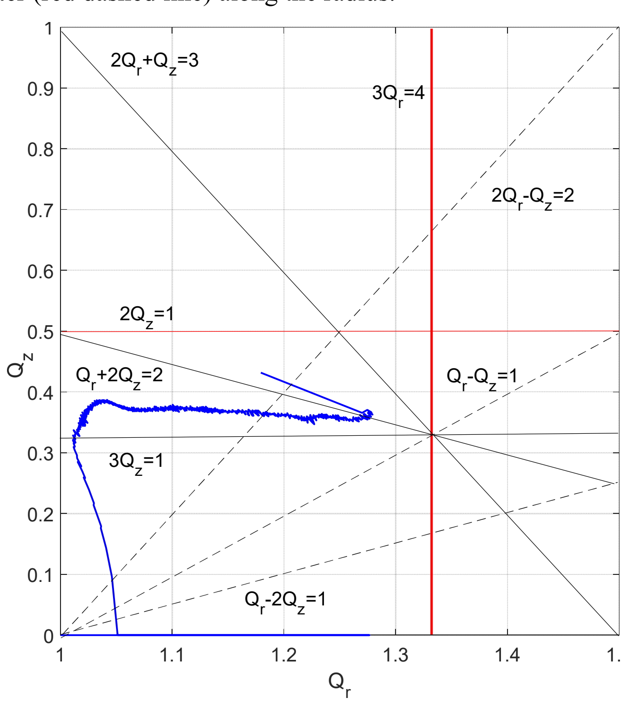

Figure 4: Working diagram.

ACCELERATING SYSTEM DESIGN

RF cavities are located at the valleys of the magnet, the geometry of the RF cavity is restricted by the size of spiral sectors. For proton acceleration, we are planning to use 4 accelerating RF cavities, operating on the 4th harmonic mode. The choice of 4th harmonic is a natural choice for a cyclotron with 4 sector and provides high acceleration rate. All four RF cavities will be connected in the centre and will be working on approximately 106.5 MHz frequency. Cavities can be equipped with an inductive coupling loop and will be adjusted by capacitance trimmers in the same way as in SC200 [11].

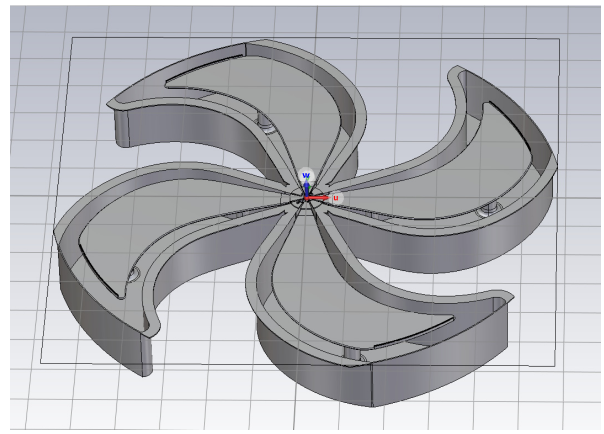

Figure 5: Overview of 3D model of RF system.

The characteristic parameters of the half-wavelength coaxial resonant cavity with two stems have been obtained from simulation in CST studio. The RF cavity resonator model for the SC230 cyclotron can be seen in Fig. 5.

Suitable accelerating frequency and voltage along radius were achieved. The calculation results of acceleration voltage are presented in Fig. 6. The value of the accelerating voltage was obtained by integrating the electric field in the median plane of the resonant cavity along the arc of a circle for each gap separately.

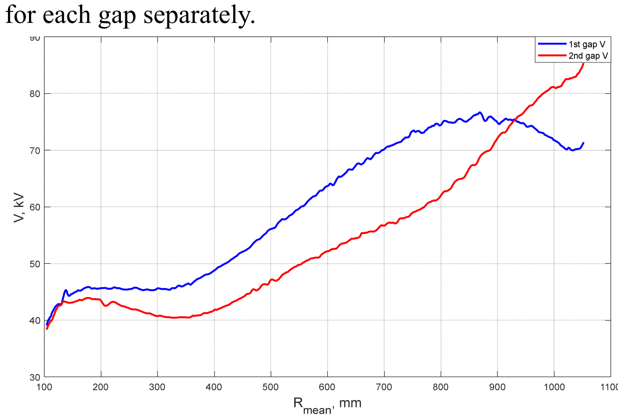

Figure 6: Accelerating voltage along radius.

Power dissipation in the model was calculated assuming the wall material is copper with a conductivity $\sigma=5.8*10^7$ 1/(Ωm). The quality factor was about 11000 and power losses of all cavities were: for storage energy 1 joule voltage in the center/extraction 40-90 kV, thermal losses are 60 kW.

EXTRACTION SYSTEM

Beam tracking is important part of cyclotron design which test the proposed solutions of all parts of accelerator.

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We simulate beam motion through whole accelerator from ion source to exit. Special attention was paid to extraction. The beam extraction for this machine will be carried out by means of 1 electrostatic deflector (ESD), located between the sectors, and 2 passive focusing magnetic channels (MC1 and MC2). We restricted electric field in deflector by the value of 100 kV/cm.

The beam, after being pulled with the deflector, passes through the accelerating RF-cavities and magnetic channels. Passive magnetic channels are located inside sector's gap, the first one decreases the average magnetic field for 600 Gs and provides gradient of 1000 Gs/cm, the second one only provides a gradient of 1700 Gs/cm.

The beam tracing though the extraction system was performed in 3D magnetic field maps which were calculated taking into account the magnetic channels and the compensating channels. The simulated computer model with correctors and extracted beam is shown in Fig. 7.

The calculated horizontal emittance at the accelerator's exit is about 8π mm mrad, whereas the vertical one is about 2π mm mrad (see particle trajectories in Figs. 8 and 9).

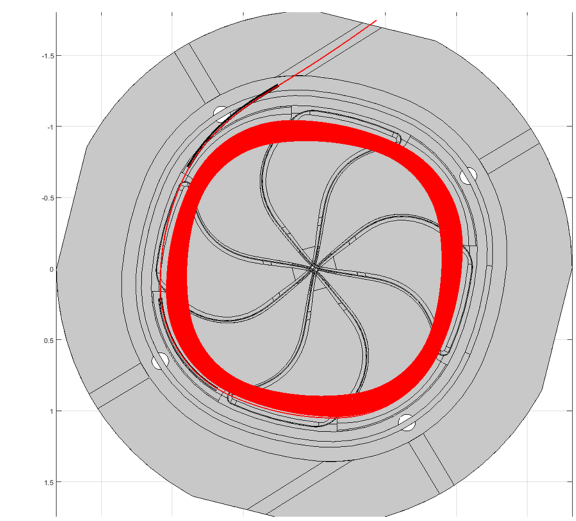

Figure 7: The beam tracing in the cyclotron structure.

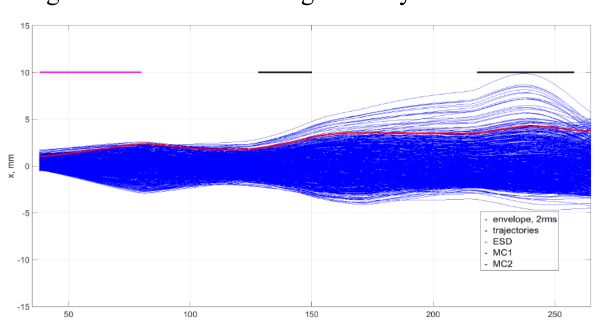

Figure 8: Radial motion of the particles through the extraction system.

CONCLUSION

The cyclotron design includes conservative and proven solutions that reduce risks and simplify engineering challenges. The MSC230 accelerator will be a source of an intense proton beam for the Medical Technical Complex of DLNP, JINR. On this basis, coupled with MTC's experience of treatment by the method of conformal therapy, opens up the possibility of equipment modernization. This is necessary for precise control and delivery of a high dose rate for studies of the FLASH therapy method.

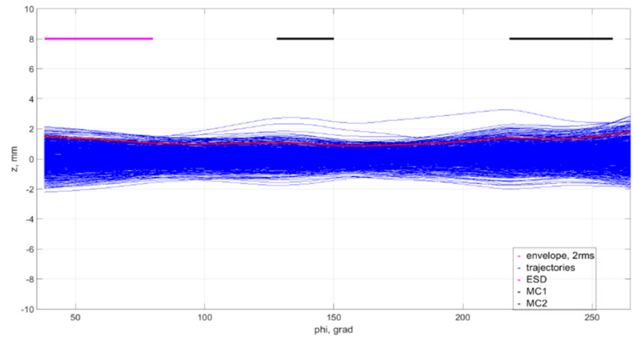

Figure 9: Vertical motion of the particles through the extraction system.

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