ACELERATOR HADRON TERAPY TECHNIQUE DEVELOPED AT JINR

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Abstract

Accelerator hadron therapy technique is one of applied researches realized at JINR. The JINR-IBA collaboration has developed and constructed the C235-V3 cyclotron for Dimitrovgrad hospital center of the proton therapy. Proton transmission in C235-V3 from radius 0.3m to 1.03 m is 72% without beam cutting diaphragms; the extraction efficiency is 62%. The main advantage of this cyclotron in comparison with serial commercial cyclotrons of IBA is related to higher current of the extracted beam.

The cancer treatment is realized in JINR on the phasotron proton beam. More than 1000 patients were treated there. A project of the demonstration center of the proton therapy is discussed on base of a superconducting 230 MeV synchrocyclotron. The superconducting synchrocyclotron is planned to install instead of phasotron in Medical Technical Complex of DLNP.

The project of the medical carbon synchrotron together with superconducting gantry was developed in JINR. The basis of this medical accelerator is the superconducting JINR synchrotron – Nuclotron. One important feature of this project is related to the application of superconducting gantry.

PROTON CYCLOTRON C235-V3

The JINR-IBA collaboration has developed and constructed the C235-V3 proton cyclotron (Fig.1) for Dimitrovgrad hospital proton center. The C235–V3 cyclotron, superior in its parameters to the IBA C235 medical proton cyclotron, has been designed and manufactured by the JINR-IBA collaboration. This cyclotron is a substantially modified version of the IBA C235 cyclotron.

Modification of the extraction system is the main aim of the new C235-V3 cyclotron [1-2]. The main feature of the cyclotron extraction system is a rather small gap (9 mm) between the sectors in this area. The septum surface consists of several parts of circumferences of different radii. The septum thickness is linearly increased from 0.1 mm at the entrance to 3 mm at the exit. The proton extraction losses considerably depend on the septum geometry. In the septum geometry proposed by JINR, where the minimum of the septum thickness is placed at a distance of 10 cm from the entrance, the losses were reduced from 25% to 8%. Together with the optimization of the deflector entrance and exit positions it leads to an increase in the extraction efficiency to 80%. The new extraction system was constructed and tested at the IBA C235 cyclotron. The experimentally measured extraction efficiency was improved from 60% for the old system to 77% for the new one.

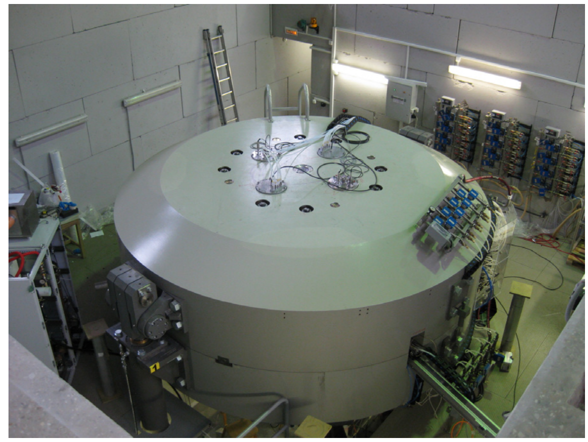

Figure 1: Cyclotron C235-V3 in JINR engineering center.

Another difference in the structure of the magnetic field for the C235–V3 cyclotron compared to an IBA C235 serial cyclotron is related to the value of the radial component of magnetic field in the median plane, bump parameters, and the minimal value of the vertical betatron frequency in the central area of the cyclotron.

The bump of magnetic field B_z in the center is used in many cyclotrons for axial focusing during the first turns, when the B_z variation is low. When the decreasing field of the bump passes to the increasing isochronous one, the dip in the axial betatron frequency Q_z could appear. In the C235-V3, Q_z decreases at a radius of 10 cm down to ~0.04–0.05.

The presence in the area of the Q_z minimum of the mean radial component of the magnetic field B_r with a level of 5 G and gradient of 5 G/cm in the median plane (Fig.2) results in the transformation of coherent motion of the center of gravity of the beam in this area into the noncoherent oscillations of individual particles and coherent oscillations of the center of gravity. The simulated axial r.m.s. (±2σ) size (Fig.3) is equal to 6 mm at B_r=0, it increases up to 12 mm at B_r corresponded to shimm thickness of 2mm (Fig.2) and 8 mm at optimized shimm thickness of 1.7 mm. In the C235-V3, the B_r component was optimized using the establish of shim correctors at the sectors.

In experiment, the r.m.s. vertical size of the beam (2σ) (Fig.4) at the radii of 15–20 cm is ~17–18 mm and becomes comparable with the vertical aperture of the accelerator of 20 mm determined by the interdee gap.

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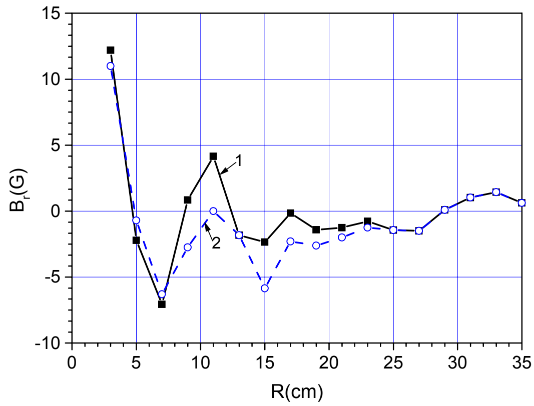

Figure 2: Distribution of average radial component in cyclotron median plane at shim thickness 2 mm (curve 1) and shim thickness 1.7 mm (curve 2).

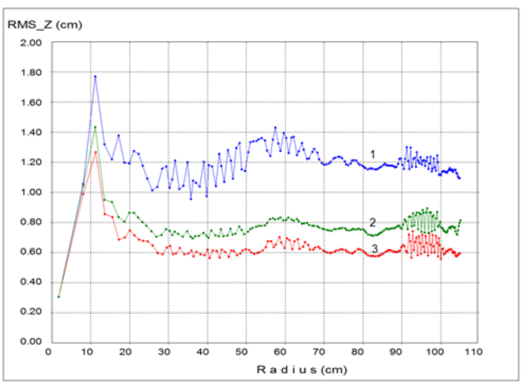

Figure 3: Simulated dependence of axial r.m.s. ($\pm 2\sigma$) size on radius: curve 1 at B_r (curve 1in Fig.2), curve 2 at B_r (curve 2 in Fig.2), curve 3 at B_r=0.

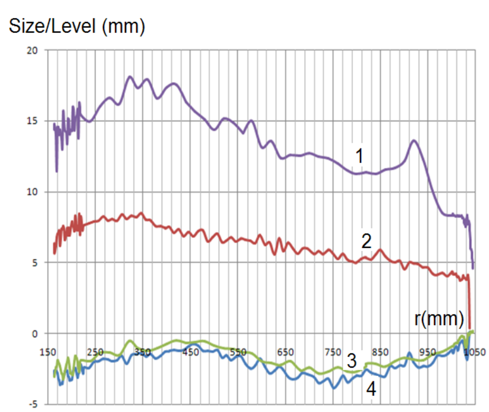

Figure 4: Experimental dependence of axial r.m.s. size (1, 2) and beam center gravity (3, 4) on radius 1, 3 – before magnet field optimization, 2, 4 after optimization.

During the further acceleration of protons in the area of large radii, where the aperture of the accelerator decreases, the appearance of the radial field in the median plane leads to beam losses because of the large amplitude of noncoherent oscillations occurring in the central area of the accelerator.

After shimm optimization, the axial size of the proton beam at radii of 15–20 cm was reduced by a factor of two and was ~7–8 mm (Fig. 4). This led to the efficiency of acceleration in the C235–V3 cyclotron being increased to 72% without the establishment of restrictive diaphragms.

DEMONSTRATION CENTER OF PROTON THERAPY

The final stage of the project is creation of the Dubna hospital center of proton therapy on basis of superconducting synchrocylotron and rotating gantry.

The first stage of the project is related to the construction of demonstration center of proton therapy on base of a superconducting 230 MeV synchrocyclotron.

The superconducting synchrocyclotron [3] is planned to install instead of phasotron in Medical Technical Complex of DLNP. The new transport channel is designed for beam delivery to the JINR medical cabin. The equipment of demonstration center of proton therapy and realized here technologies will be lay in the base of the Dubna hospital center of the proton therapy.

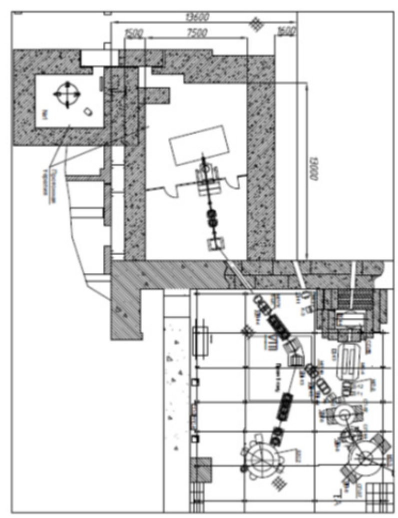

Figure 5: Scheme of synchrocyclotron with beam delivery channel and modernized medical cabin in demonstration center of proton therapy.

The synchrocyclotron S2C2 [3] (Table 1) has diameter of 2.3m. Main peculiarity of synchrocyclotron is connected with its superconducting magnets with magnetic field in hills and valleys of 5.64/5.24 T, correspondently. Four Sumitomo cryocoolers are used at realization of superconducting regime.

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Table 1. Parameters of synchrocyclotron S2C2.

Irradiation	Active
Diameter, m	2,3
Weight, t	50
Magnet	Superconducting
Average field, center/extract., T	5,64/5.24
Voltage of dee-electrodes, kV	14
RF–frequency, MHz	90-61.5
Frequency of beam pulses, kHz	1
Average current, nA	20
Proton energy, MeV	230
Energy spread, 2σ, MeV	2,5

The peculiarity of synchrocyclotron S2C2 is relatively low average current of extracted beam. At present time this current is equal to 20 nA.

SUPERCONDUCTING SYNCHROTRON FOR CARBON THERAPY

A project of the medical superconducting synchrotron (Fig.5) dedicated for the carbon therapy has been designed in JINR [4]. The basis of this medical accelerator is the superconducting JINR synchrotron – Nuclotron. The Nuclotron type straight dipole magnets were adopted for the optic of the medical synchrotron and beam delivery system. The superconducting magnets permit to reduce the accelerator electrical consumption, the size and weight of the accelerator and the carbon gantry.

The superconducting electron string ion source is planed to use for $^{12}C^{4+}$ injection in the carbon linac. The compact IH linac will apply as synchrotron injector.

The FODO structure is more preferable for injection and extraction schemes and corrections of the closed orbit distortions. The synchrotron magnetic system [4] consists of 4 superperiods, which involves 8 straight dipole magnets, 8 quadrupole lenses and multipole correctors. The maximum magnetic field in dipole magnets corresponds to 1.8 T. The multiturn injection is realized at fulfilling of the horizontal acceptance during 10-15 ion turns. The stored beam intensity is equal to 10^{10} ions C^{6+} per pulse. The working point corresponds to betatron tunes $Q_{x,z} \approx 3.25$. Nonlinear 3 order resonance $3Q_x=10$ is used for slow beam extraction. The intensity of extracted beam is equal to 10^9 pps.

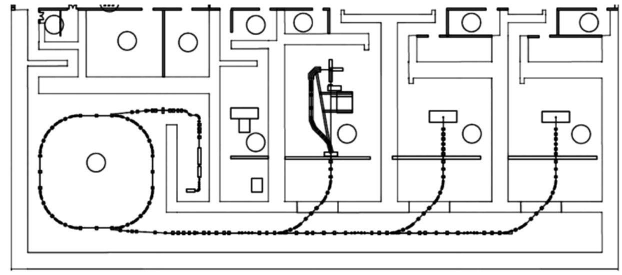

Figure 6: Layout of the carbon therapy hospital center on the basis of superconducting synchrotron.

One important feature of this project is related to the application of superconducting gantry. The superconducting magnets of low aperture (about 120 mm) are used in the gantry. The gantry consists of two 67.5° and one 90^0 bending sections, each including similar dipole magnets.

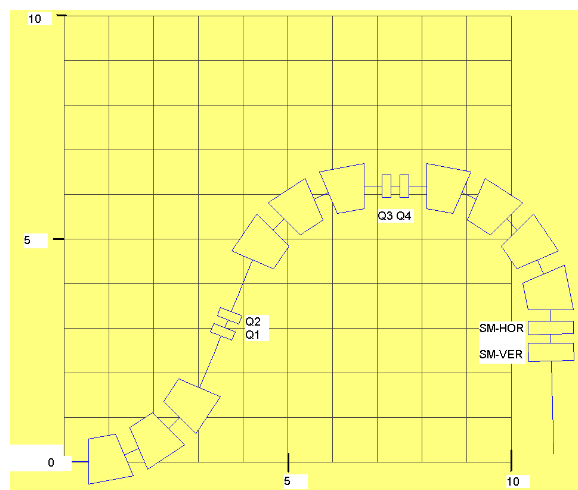

Figure 7: Layout of the JINR superconducting carbon ion gantry.

REFERENCES

[1] E.M. Syresin et al, IPAC11, S-Sebastian, (2011) 2706.
[2] S. Kostromin, E. Syresin, Physics of Particles and Nuclei Letters, v. 10, No.7 (2013) 833.
[3] W. Kleeven et al, Proceedings of Cyclotrons 2013, Canada, MO4PB02.
[4] E. Syresin et al, Particle and Nuclei Letters, v.9 (2012) 328.

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