DEVELOPMENT OF THE IBA-JINR CYCLOTRON C235-V3 FOR DIMITROVGRAD HOSPITAL CENTER OF THE PROTON THERAPY

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Abstract

The Dimitrovgrad project, the first Russian hospital center of the proton therapy, was approved in 2010. The JINR-IBA collaboration developed and constructed the C235-V3 proton cyclotron for this center. We plan to assemble this cyclotron at JINR in 2011 and perform tests with the extracted proton beam in 2012. This cyclotron is a substantially modified version of the IBA C235 cyclotron.

Modification of the extraction system is the aim of the new C235-V3 cyclotron. The new extraction system was constructed and tested. The experimentally measured extraction efficiency was improved from 60% for the old system to 77% for the new one. A new field mapping system was developed for the C235-V3 cyclotron. It consists of the axial field mapping system and an additional system for radial field B_{rav} measurements.

Further possible proton cyclotron improvement will be related to modification of the sector spiral angle for reducing coherent beam losses at acceleration. The coherent beam displacement from the median plane is defined by the vertical betatron tune Q_z. An increase in the vertical betatron tune permits reduction in the coherent losses at proton acceleration.

PROTON THERAPY AT JINR

Dubna is one of the leading proton therapy research centers in Russia [1-2]. The research synchrocyclotron with the proton energy of 660 MeV and current of 3 μA has been used for medical applications since 1967. The modern technique of 3D conformal proton radiotherapy was first effectuated in Russia at this center, and now it is effectively used in regular treatment sessions [1-2]. The irradiated dose distribution in 3D conformal proton therapy coincides with the tumor target shape with an accuracy of 1 mm. This required solving the following tasks: formation and monitoring of proton beams with the desired parameters; development of the computer codes and a technique for construction of individual collimators and boluses; development of a system for immobilization of the patient and verification of its position relative to the proton beam. About 100 patients undergo a course of fractionated treatment here every year. About 750 patients were treated by proton beams during the last 10 years (Table 1).

Table 1: Diseases Treated at JINR by the Medical Proton Beams in 2000-2011.

Disease	Number of patients
Meningioma	130
Chordoma, chordosarkoma	27
Glioma	48
Acoustic Neurinoma	9
Astrocytoma	33
Paraganglioma	5
Pituitary Adenoma	22
AVM	63
Brain and other metastases	59
Other head and neck tumors	194
Melanoma	11
Skin diseases	45
Carcinoma metastases of the lung	9
Breast cancer	46
Prostate Adenoma	1
Sarcoma	14
Others	28
Total	744

C235-V3 PROTON CYCLOTRON

The Federal Medico-Biological Agency in collaboration with JINR developed the Dimitrovgrad project of the first hospital proton center in Russia. The center (Fig.1) consists of two gantry systems, a medical treatment room with a fixed beam used at the treatment angles of 0^0 and 60^0, an eye treatment room and a PATLOG system of preliminary patient positioning. The JINR-IBA collaboration has developed and constructed the C 235-V3 proton cyclotron for this center.

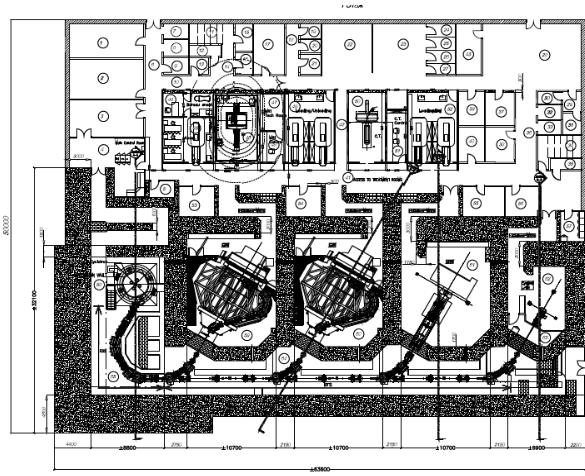

Figure 1: Layout of the Dimitrovgrad proton therapy hospital center.

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 aim of the new C235-V3 cyclotron [3-4]. 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 (Fig.2).

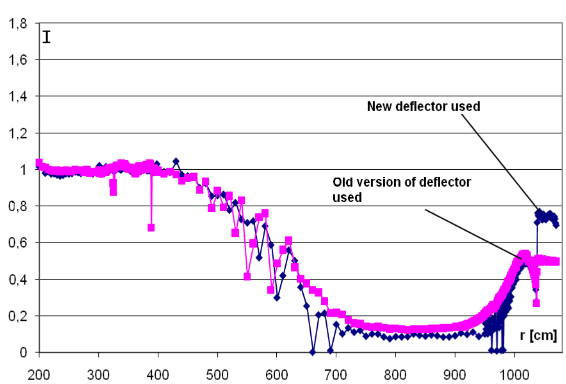

Figure 2: Proton beam extraction in the C235 cyclotron with the old IBA deflector and the new electrostatic deflector.

Further optimization [3-4] of the proton cyclotron C235-V3 proposed by JINR will oriented on modification of the sector spiral angle at R>80 cm reducing the coherent beam losses at acceleration caused by larger vertical betatron tune Q_z (Fig. 3). The coherent beam displacement z from the median plane is defined by the vertical betatron tune: $z \propto Q_z^{-2}$. At Q_z~0.2 the vertical coherent beam displacement is 2.5 mm in presence of the magnetic field radial component B_r~2G, and having free axial oscillation amplitude of 2-3 mm in the proton beam it can cause significant beam losses due to a smaller sector gap in the C235 cyclotron. An increase in the vertical betatron tune from Qz~0.2 to Q_z~0.4 permits to decrease the coherent beam displacement by a factor of 4 to 0.6 mm at the same value of B_r and to reduce the losses at proton acceleration by a factor of 3.

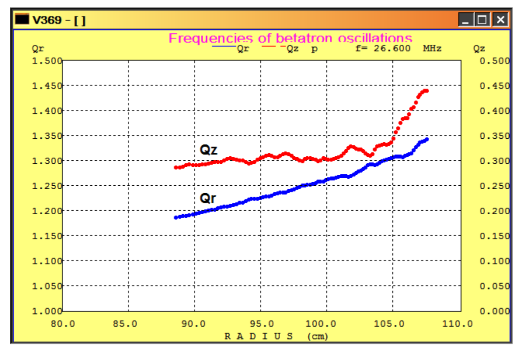

Figure 3: Dependence of betatron tunes on the radius for the optimized sector spiral angle.

The advantages of the medical proton cyclotron are simplicity, reliability, small size, and most importantly the ability to modulate rapidly and accurately the proton beam current (Fig. 4). The current modulation of the extracted proton beam at a frequency up to 1 kHz is most advantageous with Pencil Beam Scanning and Intensity Modulated Proton Therapy. The energy of the extracted beam in the cyclotron is fixed. However, the fast proton energy variation of 1.5 MeV within 100 ms is easily performed during active cancer treatment by using a wedge degrader. This energy variation rate is faster than in the typical synchrotron regime.

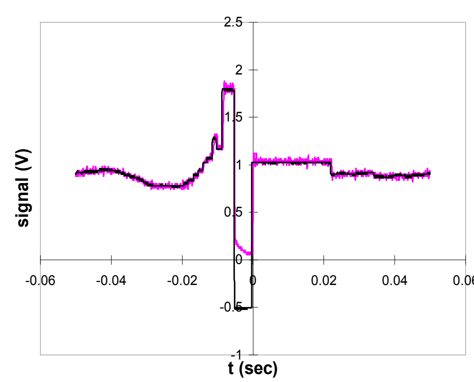

Figure 4: Beam intensity variation at the IBA C235 proton cyclotron.

CYCLOTRON ASSEMBLING AND MEASHUREMENTS AT JINR

The assembling of the proton cyclotron started in June 2011 at JINR. A special engineering center (Fig. 5) was created at JINR in 2008-2010 testing of the medical accelerator equipment. The DLNP proton therapy cyclotron and the FLNR cyclotron used for blood cascade plasma filtration are assembled and tested here at present.

Figure 5: JINR engineering centre for the assembling and testing of the medical accelerator equipment.

The magnetic measurements and shimming of the magnetic field in the proton cyclotron started in July 2011. The axial magnetic field mapping is based on the Hall probe technique. The special platform was designed for fabrication of all sector edges simultaneously. The accuracy of the mechanical fabrication of the sector edge surface modification is about ±20 μm. Precision geometrical measurements of the sector edges at the shimming of the magnetic field are produced by the Eclipse 3D Carl Zeiss machine. The new JINR calibration magnet applied for magnetic field up to 2.9 T was implemented in the scheme of the magnetic measurements.

The new equipment [5] (Fig. 6) with the search coils for measurements of the average radial component B_{rav} and for correction of the magnetic field median plane in the C235-V3 cyclotron was developed and tested at JINR. The average radial component of the cyclotron's magnetic field is the first among the most dangerous causes for the vertical beam offset and the most difficult part of the magnetic field measurement procedure. The B_{rav} measurements are based on integration of the difference between the vertical components in two planes at the distances $\pm a$ from the median plane. To get a full magnetic field map, it is necessary to use a set of coils with the designed set of radii. The B_{rav} system consists of the measurement disk with 35 search coils and the alignment and pneumatic system for the vertical shift of the disk. The accuracy of the measurement of $B_{r\ av.}$ is about 0.2-0.3 G.

Figure 6: Measurement disk with search coils for the C235-V3 cyclotron.

It is planned that the magnetic measurements and shimming of the magnetic field will be finished at the beginning of 2012. After the assembling of the vacuum chamber and the RF cavity we plan to perform tests with the extracted proton beam. The cyclotron will be delivered to the Dimitrovgrad proton therapy center at the end of 2012.

REFERENCES

[1] O.V. Savchenko, J. Medical physics (2007), № 3-4.

[2] A.V. Agapov et al, Particle and Nuclei Letters, № 6 (2005), 80-86.

[3] G. Karamysheva et al, Particle and Nuclei Letters, v.7, №4 (2010) , 507-510.

[4] E.M. Syresin et al, Particle and Nuclei Letters, v.8, №4, (2011), 635-646.

[5] G. Karamysheva, N. Morozov, P. Shishlyannikov The 19th International Conference on Cyclotrons and their Applications, Lanzhou, P.R.China, 2010, MOPCP077.