ISOCHRONOUS CYCLOTRON C-250 FOR PROTON THERAPY APPLICATION

Yu.G. Alenitsky, S.B. Vorozhtsov, A.A. Glazov, N.L. Zaplatin, S.A. Kostromin, G.A. Karamisheva, L.M. Onischenko
Joint Institute for Nuclear Research, Dubna, Russia
E-mail: alen@nusun.jinr.ru

Project of C-250 – cyclotron for proton therapy is considered. Energy of the extracted form cyclotron beam was increased according to medical requirements up to 250 MeV. 4-fold and compact types of magnet yoke were studied by 3D computer magnetic field calculations. The ability of optimal combination of the magnet yoke, HF and extraction systems of the cyclotron based on the dynamics of the proton beam in calculated magnetic and accelerating field is under discussion. Dubna scientific medicine center is under development since 1967 on the base of the proton beam of LNP JINR Phazotron. Proton beam with energy E_p~170 MeV and intensity I~0.1 μA is used for patients irradiation. Proposal of the cyclotron with the same beam characteristics was published earlier [1-4].

PACS: 29.20.Hm

INTRODUCTION

C-235-cyclotron was created by IBA (Belgium) for the beam therapy (energy of protons 235 MeV), number of such a machines work in medical centers. ACCEL Instruments GmbH [5] created superconducting cyclotron on energy of protons 250 MeV for the medical program PROSCAN PSI. In the given work offered to create cyclotron C-250p for acceleration of protons up to fixed energy E_p ~ 250 MeV. This energy is necessary to irradiate patients in anti gantry inside the special fixing capsule, were beam losses part of its energy. In the Table parameters proton cyclotrons C-235 (IBA), C-250 (ACCEL), and C-250p are given.

MAIN PARAMETERS OF CYCLOTRONS

Parameters of cyclotrons for proton therapy

Parameters	C–235 IBA	C-250 ACCEL	C-250p JINR LNP
Energy of protons (MeV)	235	250	~250
Average magn. field (T): in center in extraction radii	 1.739 2.165	 ~4 ~4	 1.41 1.79
Extraction radius (m)	1.08	~0.9	1.4
Magnetic field at extraction radius (T): hill valley	 3.09 0.985	 4.0 1.6	 2.80 1.10
Gap (cm): valley hill	 60 9.6…0.9	 -	 40 4
Number of sectors	4	4	4
Main coil ampere turn (kA)	525	-	330
Power consumption (kW)	190	40(cooling)	170
Weight of magnet (T)	210	90	300

CYCLOTRON MAGNETIC SYSTEM

The diameter of magnet poles equals 3m. Modeling of the cyclotron magnetic system was carried out by means of the code *Radia ver. 4.098* [6], which works under *Mathematica* platform and calculates magnetic field of the three-dimensional magnetic systems by a method of the integrated equations.

In work [3] the various types of yoke are considered, it was shown, that the magnet with four opposites yoke is more convenient for service, such design is accepted in the present project. As a material of a magnet it is supposed to use steel - 10.

The magnetic system consists of sectors, poles, horizontal and vertical yokes, current coils, the circuit of a magnet is shown in Fig.1. In opposite valleys through 90° the high-frequency resonators are located.

The variation of a magnetic field creates four pairs flat sectors located symmetrically on poles (see Fig.1) from above and from below. A gap between sectors is constant size of 40 mm. The average magnetic field, growing with radius, is created at the expense of increase of the azimuth extent of sectors. The vertical stability is reached at the expense of high sectors and them spirality, the extent of sectors spirality is increased at the expense of internal border, thus, increasing spirality and, accordingly, frequency of axial fluctuations.

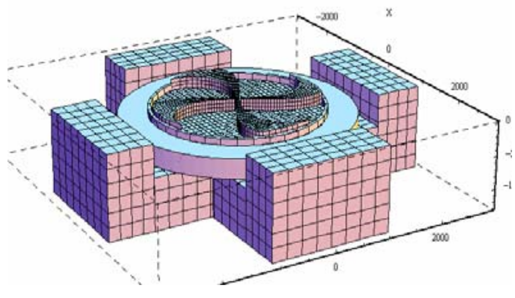

Fig.1. Computing model, lower part of magnet

For the consumer the important characteristics of installation are both the sizes and a technology of manufacturing of the project, and both operational conditions

- consumed energy and cost of service. We propose on the base of our results, that the offered project C-250p with four symmetry return yoke (Fig.1) is optimum and that such installation can be created as a pilot project of our institute.

The complete angular extent of one sector on a pole is 55º, thus in valleys there is an opportunity to place 42º rectilinear resonators.

BEAM DYNAMICS

In the Figs.2 and 3 the dynamic characteristics of a beam in the magnetic field calculated for magnet with yoke 4-fold back yoke are shown. The frequencies of axial and radial motion are in allowable limits.

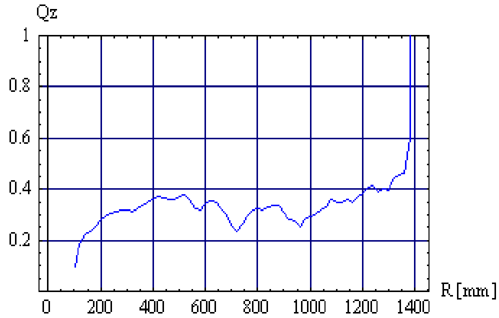

Fig.2. Dependence of frequency of free axial oscillations via radius

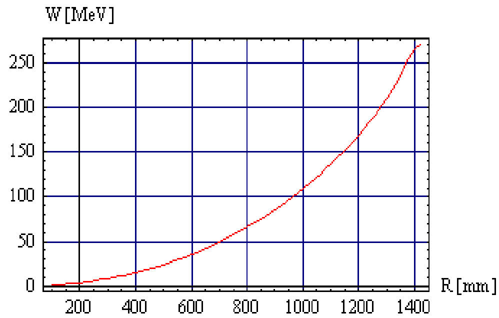

Fig.3. Dependence of energy of protons via radius

RADIOFREQUENCY SYSTEM

Rectilinear on radius the accelerating resonators which have angular extent 42º and 30º dee are used. They are located in valleys, where the gap between poles is 400 mm. The adjustment and excitation of resonators is carried out through the coaxial lines. The central rod located from above and from below is used for the dee support. Parts of the lines, which leave for the size of 400 mm are placed in the channels of poles of the magnet. The basic parameters of high-frequency system were obtained making use a three-dimensional code. For excitation of the accelerating system it is proposed to use the standard high-frequency generator on the suitable capacity and frequency 81.8 MHz working on linkage feeder.

EXTRACTION SYSTEM

The extraction system consists of electrostatic deflector, passive magnetic channel (MC1) and two focusing quads (QL1 and QL2). Beam portraits at the deflector entrance were obtained during protons acceleration simulation (see Figs.4 and 5)

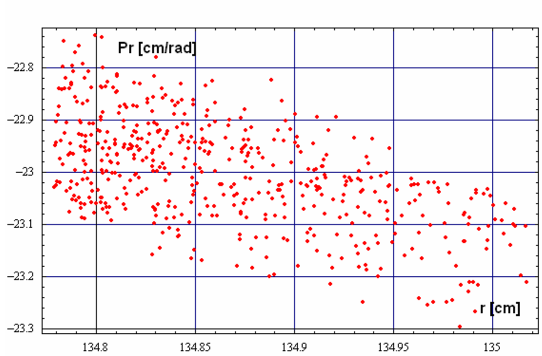

Fig.4. Portrait of the beam on (r,Pr)-phase plane at the deflector entrance

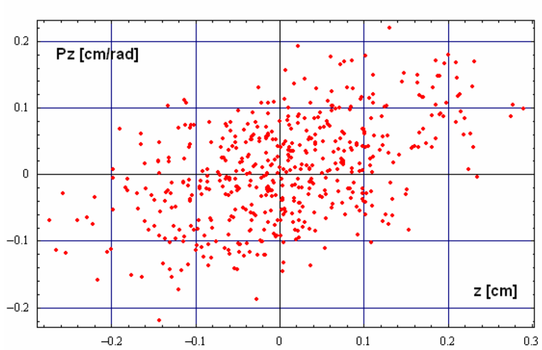

Fig.5. Portrait of the beam on (z,Pz)-phase plane at the deflector entrance

Using these data tracking of the beam up to the beginning of the transport line has been carried out. Action of the electrostatic deflector and magnetic corrector as well as quad-lenses was taken into account in the simulations. Plane view of the extracted beam is presented in Fig.6.

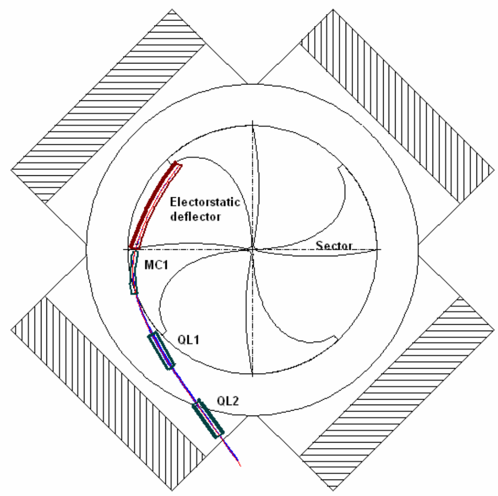

Fig.6. Plane view of the extracted beam

Extracted beam rms-envelopes are presented in Fig.7.

One can see that extracted beam transverse size doesn't exceed 2.5x4 cm.

Calculations give that the beam losses are:

- 35% – on the top of the septum and on the its external (looking on the circulating beam) side;
- 14% – on inner surfaces of the septum and high-voltage electrode (inside the deflector).

Thus, the efficiency of the extracting system is ~51% (there are no losses on the MC1, QL1 and QL2).

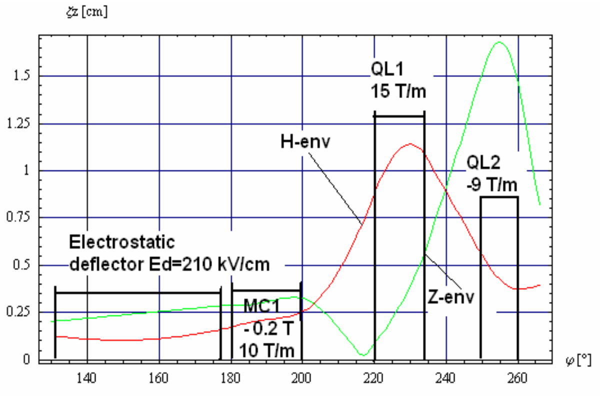

Fig.7. Extracted beam rms-envelopes and optic parameters of the extraction system elements

OTHER CYCLOTRON SYSTEMS

The design of the cyclotron vacuum chamber depends on the form of the return yoke. In our opinion the magnet with four return yokes is more convenient to make technological service of the cyclotron.

Diagnostics of the parameters of accelerated beam is carried out by three probes, one of them is on the entrance of extraction channel. On the exit of electrostatic section of the channel the fourth short probe is arranged.

In connection with a rather low required intensity of the beam in this cyclotron, it is possible to use a Penning ion source, which is moved from above in the centre of cyclotron. Acceleration and the formation of the beam during the first turns is carried out with the help of special central optics.

CONCLUSIONS

The physical consideration of proton cyclotron on the energy of about E_p ~250 MeV was given. This cyclotron will provide all scientific and medical programs on the medical beam of Dzhelepov Laboratory of Nuclear Problem, Joint Institute for Nuclear Research.

REFERENCES

1. Yu.G. Alenitsky, et al. Cyclotron for beam therapy application // *XIX Russian Particles Accelerator Conf. Proc*. Dubna, 2005, p.162-164.
2. Yu.G. Alenitsky, et al. Cyclotron for therapy application // *ICAA"05 Proc*. SPbUniv. 2005, p.228-232 (in Russin).
3. Yu.G. Alenitsky, et al. Cyclotron for therapy application // *XX Russian Particles Accelerator Conf. Proc.* Novosibirsk, 2007, p.162-164 (in Russin).
4. Yu.G. Alenitsky, et al. Cyclotron for therapy application // *Applied Physics.* 2005, №5, p.50-54 (in Russin).
5. A.E. Geisler, J. Hottenbacher, H.U. Klein, et al. // Commissioning of the Accel 250 MeV proton cyclotron // *Proc. of the Eighteenth International Conf. Cyclotrons and Their Applications.* 2007, p.9-14.
6. P. Elleaume, O. Chubar, J. Chavanne. Computing 3D Magnetic Field from Insertion Devices // *Proc. of the PAC97 Conference.* 1997, p.3509-3511.

Статья поступила в редакцию 07.09.2009 г.

ИЗОХРОННЫЙ ЦИКЛОТРОН С-250 ДЛЯ ПРОТОННОЙ ТЕРАПИИ

Ю.Г. Аленицкий, С.Б. Ворожцов, А.А. Глазов, Н.Л. Заплатин, С.А. Костромин, Г.А. Карамышева, Л.М. Онищенко

Обсуждается проект циклотрона С-250, предназначенного для протонной терапии. Энергия пучка, выведенного из циклотрона, увеличена до 250 МэВ. Рассчитан компактный магнит с четырьмя вертикальными стойками. Обсуждается оптимальное сочетание конструкции магнита, высокочастотной системы и системы вывода на основе расчета динамики движения пучка в расчетном магнитном и электрическом полях. Дубненский научный медицинский центр на основе фазатрона ЛЯП ОИЯИ развивается с 1967 года. Для лечения пациентов используется пучок протонов с энергией E_p~170 МэВ и интенсивностью I~0.1 мкА. Различные аспекты предложения для создания циклотрона для медицинских целей с указанными параметрами обсуждались ранее [1-4].

ІЗОХРОННИЙ ЦИКЛОТРОН С-250 ДЛЯ ПРОТОННОЇ ТЕРАПІЇ

Ю.Г. Аленицький, С.Б. Ворожцов, А.А. Глазов, Н.Л. Заплатін, С.А. Костромін, Г.А. Карамішева, Л.М. Онищенко

Обговорюється проект циклотрону С-250, призначеного для протонної терапії. Енергія пучка, виведеного з циклотрона, збільшена до 250 МеВ. Розраховано компактний магніт з чотирма вертикальними стійками. Обговорюється оптимальне поєднання конструкції магніту, високочастотної системи і системи виводу на основі розрахунку динаміки руху пучка в розрахунковому магнітному та електричному полях. Дубненський науковий медичний центр на основі фазатрона ЛЯП ОІЯД розвивається з 1967 року. Для лікування пацієнтів використовується пучок протонів з енергією E_p ~ 170 МеВ і інтенсивністю I ~ 0.1 мкА. Різні аспекти пропозиції для створення циклотрона для медичних цілей з вказаними параметрами обговорювалися раніше [1-4].