CYCLOTRON FOR BEAM THERAPY APPLICATION

Yu. G.Alenitsky, S.B.Vorozhtsov, A.A.Glazov, G.V.Mytsyn, A.G.Molokanov, N.L.Zaplatin, G.A.Karamysheva, S.A.Kostromin, L.M.Onischenko, E.V.Samsonov,
DLNP, Joint Institute for Nuclear Research, Dubna, Russia

Abstract

The proton beam for radiation therapy application in Russia for the first time [1] was created in 1967 on the base of Phasotron (Laboratory of Nuclear Problems JINR). Now an energy of extracted proton beam is Ep=680 MeV, intensity Ip=3 mkA [2].

A six–cabin medical facility has been developed and put into operation on this beam [3]. Now in practice of treatment on medical beam LNP JINR the most frequently used beam has the energy 170 MeV and current Ip ~ 0.1 mkA [4, 5].

We suppose that it is more rational to create a new cyclotron with required parameters of beams and to arrange it in the LNP JINR for use in a medical complex. The design proton beam energy is: Ep~200 MeV[6]. Cyclotron is proposed on the basis of compact fore sectors magnet with ring opposite yoke having a diameter of poles Ø=3 m. Two dees accelerating system is located in valleys.

THE BASIC PARAMETERS OF CYCLOTRONS FOR MEDICAL APPLICATION

Now IBA and SHI firms create the project [7] of the cyclotron on energy of protons 235 MeV especially for the therapy and some such accelerators already were put into operation. Firm ACCEL Instruments GmbH [8] develops superconducting cyclotron on energy of protons 250 MeV.

Table 1: Main parameters of cyclotrons

PARAMETER	**C – 235** IBA	**C-250** ACCEL	**C-190(H$^-$)** JINR LNP	**C-200p** JINR LNP
Energy of protons (MeV)	235	250	70-190	~200
Average magnetic field (T) At center At extraction radii	 1.739 2.165	 ~4 ~4	 0.77 0.92	 1.33 1.64
Extraction radius (m)	1.08	~0.9	~2.1	1.4
Magnetic field at extraction radius (T) hill valley	3.09 0.985	4.0 1.6	0.6 1.1	2.65 0.95
Gap (mm) valley hill	600 96-9	 -	380 140	400 50
Number of sectors	4	4	4	4
Main coil ampere turn (kA)	525	-	150	340
Power consumption (kW)	190	40(cooling)	120	170
Weight of magnet (T)	210	90	400	300

alen@nusun.jinr.ru

In the table 1 some parameters of cyclotrons C- 235 (IBA) [7], C-250 (ACCEL) [8], C190 (H-) [6] and C200p are given. Cyclotrons given in the table 1 differ by a level of the used magnetic field and by correspondent technical parameters. The most important characteristics of the installation are the size and technology of manufacturing of the project (cost), and operational conditions – energy consumption and cost of service. We consider, for our conditions, that the offered project C200p is optimum because of the installation will be able to be manufactured inside our institute, and will have a pretty low cost.

THE BASIC PARAMETERS OF C200p CYCLOTRON

Magnetic System

Isochronous cyclotron for proton therapy application is supposed to be created on the basis of a compact four sectors magnet with ring opposite yoke having an outer diameter 5.2 м and height 2.4 m.

A computer modeling of cyclotron magnetic system was carried out with the help of the code Radia [9], which works in the system of Mathematica and calculates the magnetic field of three-dimensional magnetic systems by a method of the integral equations. A plane view on the various cyclotron systems is shown in figures 1.

A general view of mathematical model of a bottom part of the magnet is shown in figure 2.

The magnetic system consist of sectors (1), poles (2), ring top and bottom horizontal yokes (3), coils (4) and vertical yoke (5) (see figs. 1). The required configuration of the magnetic field is formed using a spiraled and angular extent of sector shims depending on radius.

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

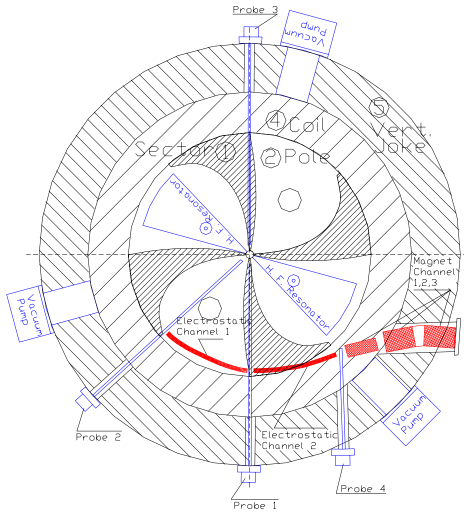

Figure 1: Plane view of the magnetic system of proton cyclotron C200p

Beam Dynamics

In figs. 4 -7 the dynamic characteristics of beam in the magnetic field are given. The betatron frequencies of axial and radial motion (fig. 4) are in allowable limits

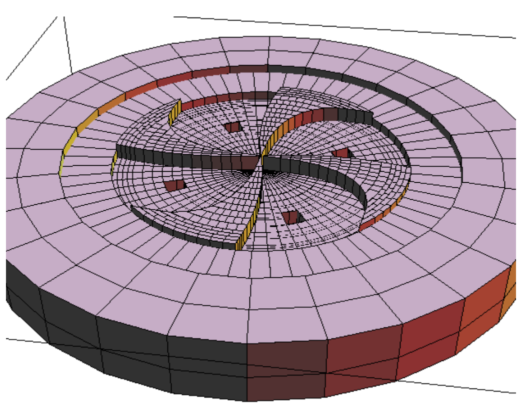

Figure 2: Computer model of the magnetic system of C200p (bottom part of the magnet, hole for coaxial line of RF system can be seen)

Working point diagram along the acceleration in C200p is presented in figure 5. The point to point distance is 10 MeV. The most dangerous resonance Q_r-Q_z=1 is crossed two times at energies 130 and 170 MeV. Modeling of particle dynamics showed that no axial amplitude increase observed after the resonance (see below) if no skew harmonics presented in magnetic field map. Further computations have to define permissible limits of such harmonics.

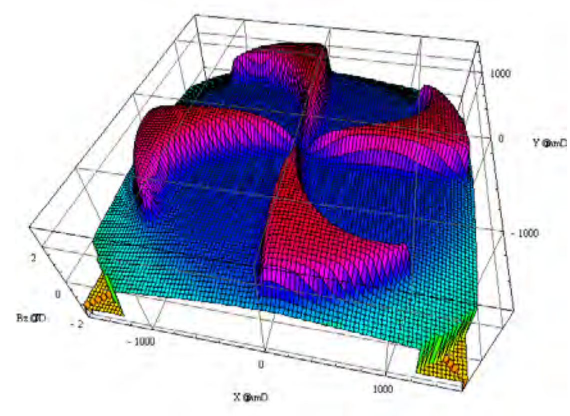

Figure 3: Magnetic field map computed by the RADIA code

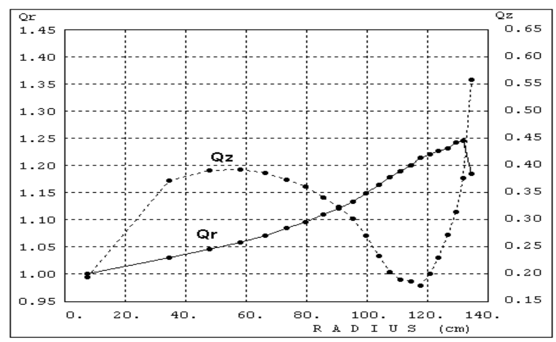

Figure 4: Free betatron frequencies along radius

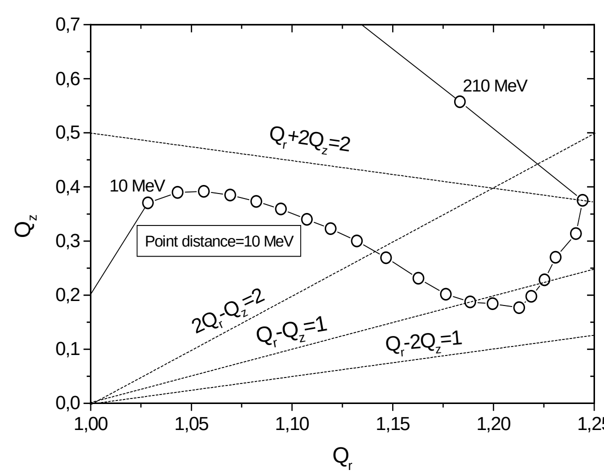

Figure 5: Working point diagram of C200p

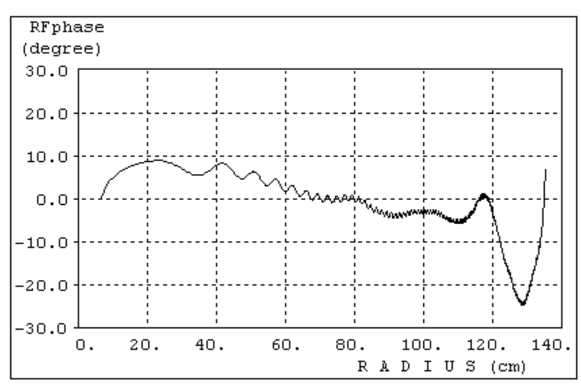

Figure 6: Phase motion of central particle

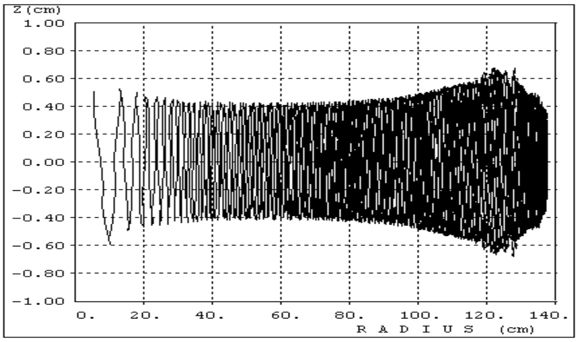

Figure 7: Axial motion of one particle

Phase motion of central particle computed along the acceleration (see fig. 6) shows good accuracy of a isochronous field. Particle resonance orbital frequency is 20.4545 MHz. Axial particle motion along acceleration in magnetic field with no skew harmonics is shown in fig. 8. Amplitude of particle radial oscillation was 5 mm during this computations. Changing of axial oscillations amplitude corresponds to the dependence of axial betatron frequency on the radius.

Radiofrequency System

Rectilinear on radius the accelerating resonators and dees have angular extent 42º and 30º, respectively. They are located in valleys between sectors (see figure 1), where the gap between poles is 400 mm. The adjustment and excitation of resonators is carried out through coaxial lines. The central rods used for dees support are located above and below them. A view of high-frequency cyclotron system is given in fig. 8. The basic parameters of high-frequency system designed by a three-dimensional program ANSYS are given in the table 2.

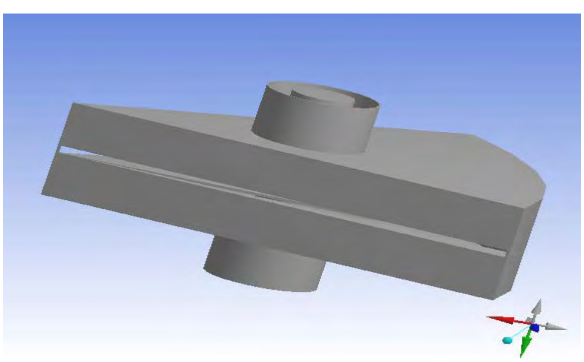

Figure 8: RF system with coaxial lines above and bellow

For excitation of accelerating system it is expedient to use a standard high-frequency generator on a suitable power and frequency working on a linkage feeder.

Extraction System

A general view of extraction system is shown in fig. 1. It consists of beam radial enhancement system, electrostatic sections, deflecting and focusing magnetic sections. In the present work the preliminary result of computation of extraction trajectory is shown. To define the parameters of radial enhancement system and the extraction channel the additional efforts are needed. The energy of the extracted beam in the table 1 is given approximately. The exact value of energy will be determined after corresponding computation of the extraction system.

Table 2: The main parameters of accelerating system

Resonance frequency (MHz)	81,8
case dimensions	
Radial (Rmax) (mm)	1500
Height (mm)	400
Azimuth span (°)	50
dimensions Δ-electrod (dee)	
Max.rad.(Rmax)(mm)	1400
Height (mm)	50
Aperture (mm)	30
Azimuth span (°)	30
Accelerating gap (°)	6
Coaxial line dimensions	
Between clothe contact plates (mm)	800
Radius of coaxial line inner (mm) outer (mm)	 100 180
From center of cycl. to axes (mm)	750

CONCLUSIONS

The physical substantiation for proton cyclotron on energy of the beam E_p ~200 MeV is given. This cyclotron will supply performance of all scientific and medical programs on the medical beam of Dzhelepov Laboratory of Nuclear Problem, Joint Institute for Nuclear Research.

The creation of cyclotron for the medical centers in other interested organizations is possible on the basis of proposed project.

REFERENCES

[1] V.P.Dzhelepov, V.I.Komarov, O.V.Savchenko. Preprint JINR 16-3491, Dubna, 1967; Med. Radiology 1969, №4.

[2] V.P.Dzhelepov, V.P.Dmitrievsky, L.M.Onischenko, Preprint JINR , P9-85-358, Dubna, 1985.

[3] Abazov V.M.et al, Radiation therapy with JINR Phasotron Beams, Dubna, Second Edition,JINR- 9-96-387, 1996.

[4] Abazov V.M. et al, Medical facility for radiation therapy with JINR Phasotron beams, E18-94-112, Dubna, 1994.

[5] Stopping Powers and Ranges for Protons and Alpha Particles, ICRU Report 49, Bethesda, USA, ISRU (1993).

[6] Yu.G.Alenitsky at al, Variable energy cyclotron for proton therapy application. Preprint JINR P9-2004-32, Dubna, 2004.

[7] http://www.shi.co.jp/quantum/index.html; http://www.iba-worldwide.com/root_hq/index.html

[8] M. Schillo. The ACCEL Superconducting Cyclotron: A Driver for Proton Therapy. Abstracts of PTCOG-38, Chester, UK, 2003, p.10.

[9] P. Elleaume, O. Chubar, J. Chavanne, "Computing 3D Magnetic Field from Insertion Devices", Proc. of the PAC97 Conference May 1997, p. 3509-3511.