SPECIALISED CYCLOTRON FOR BEAM THERAPY APPLICATION

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Abstract

Dubna scientific medicine center is under development since 1967 on the base of the proton beam of LNP JINR Phazotron.[1] Proton beam with energy E_p~170 MeV and intensity I~0.1 mkA is used for patients irradiation. Proposal of creating of the cyclotron with the same beam characteristics was reported earlier at the conferences RUPAC04 [2], ICAA05 [3] and printed in magazine [4].

The development of this project is considered in this paper. Behavior of the different types of magnet yoke was studied by computer modeling and optimal form of the yoke was chosen taking into account the cost of elements manufacturing and assembling of the electromagnet. The ability of optimal combination of the magnet yoke, HF and extraction systems of the cyclotron is under discussion taking into account the dynamics of the proton beam in calculated magnetic and accelerating field.

Introduction

A six–cabin medical facility has been developed in LNP JINR and put into operation on the base of Phazotron beam. Original methods and technologies for forming dose fields have been developed and successfully applied in a clinic as well as new methods of reconstructive proton tomography for treatment of patients with medical phasotron beams. In practice of treatment on the medical beam LNP JINR now the beam with energy 170 MeV and current Ip ~ 0.1 mkA most frequently is used.

All attempts to reduce the beam energy extracted from Phasotron need the significant financial expenses for change its magnetic and accelerating systems. We suppose, that it is more rational to create new cyclotron with required parameters of beams and to establish it in the LNP JINR to use it in the medical complex. Under the offered project it is also possible to create cyclotron for other interested organizations.

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THE BASIC PARAMETERS OF CYCLOTRON FOR PROTON THERAPY APPLICATION

Magnetic System

Modeling of the cyclotron magnetic system was carried out with the help of the program Radia ver. 4.098 [5], which works in computation system Mathematica and calculates a magnetic field of three-dimensional magnetic systems by a method of the integrated equations. As a material of a magnet the steel - 10 was used.

Isochronous cyclotron for proton therapy is proposed to be created on the basis of a compact four sectors magnet with circle return yoke having an outside diameter 5.2 м and height 2.4 m. Some types of the return yokes were calculated to compare them.

The profile view and scheme of the various opposite yokes of the cyclotrons magnet are shown in fig. 1. The poles, sectors and the coils for these magnets are the same and the difference is only in the yoke.

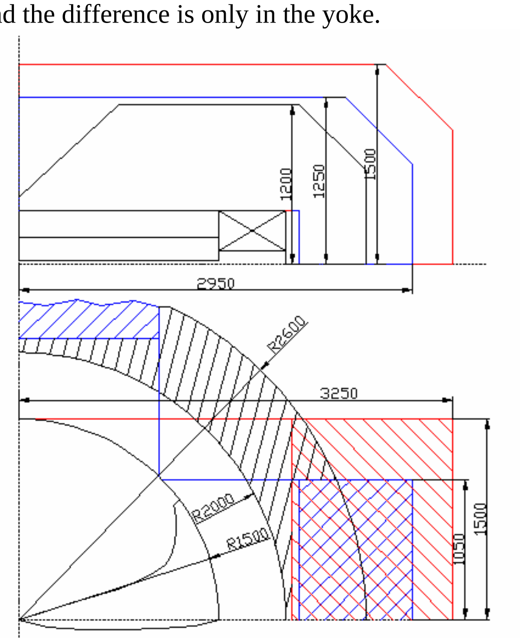

Figure 1: Profile and plan view of the magnet with various return yokes.

The general view of mathematical model of the bottom part of the such types of magnets are shown in the

Figures 2a, 2b, 2c. The required configuration of a magnetic field is formed by means of spiral and angular extent of the sector shims depending on radius.

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

Consideration of the magnets (fig. 2a, 2b, 2c) has shown that the difference caused by the return yoke form does not exceed 150 G of average magnetic field. The formation of a field in such range can be made by means of special steel shims.

For the consumer the important characteristics of installation are the sizes and technology of manufacturing of the project (cost), and operational conditions - consumed energy and cost of service. We propose using our conditions, that the offered project C220p with four symmetry return yoke (fig. 2b) is optimum and that the such installation can be made as a pilot project of our institute.

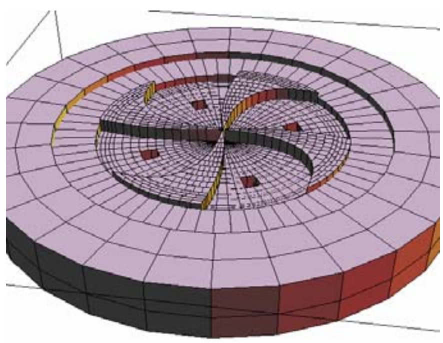

Figure 2a: Magnet system of proton cyclotron C220p plane view (circle return yoke).

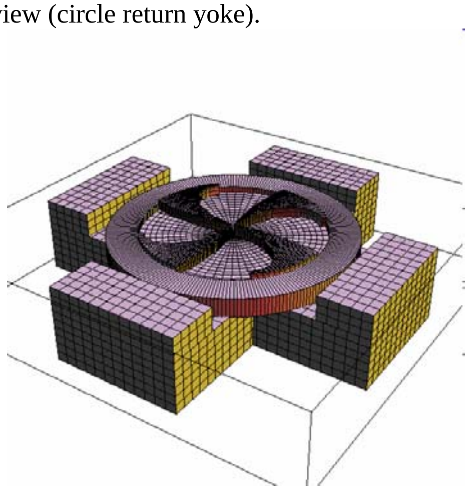

Figure 2b: Magnet system of proton cyclotron C220p plane view (four symmetry return yoke).

To check the calculations done with the program Radia, we have carried out the calculations of same configurations of the magnet by means of TOSCA code. In Fig. 3 a comparison of the results Radia - TOSCA is shown. It is visible, that the difference does not exceed 15 mT. Such field it is possible to form by means of iron shimming elements.

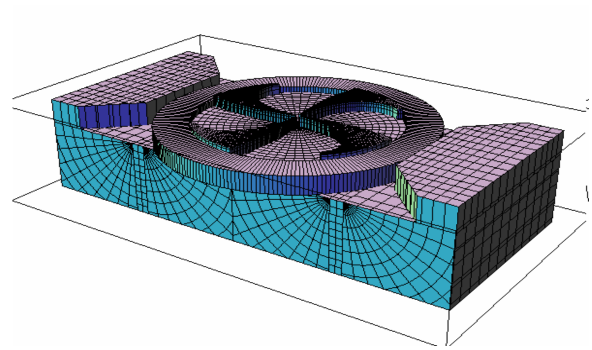

Figure 2c: Magnet system of proton cyclotron C220p (two symmetry return yoke).

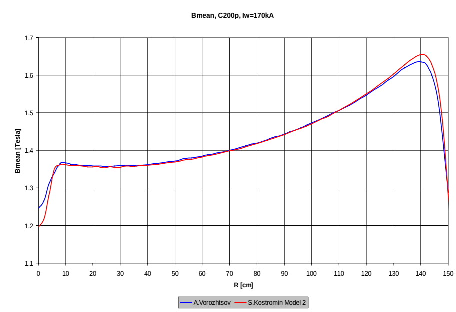

Figure 3: Comparison Radia (Mathematica) – TOSCA calculation of magnet system with sector shims.

The average magnetic field of adjusting steel elements, which can be arranged on an internal surface of sector shims, represents a difference of two calculations with design sectors and from the angular extent increased by one degree sectors. The obtained field is given in Fig. 4.

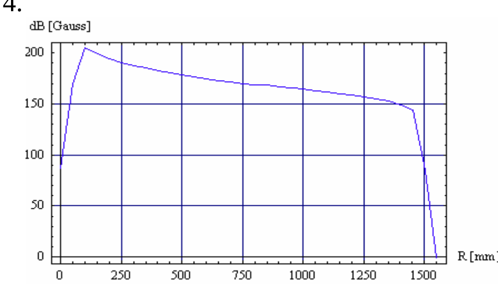

Figure 4: Calculated field from the angular extent by one degree sectors.

Beam Dynamic

In figs. 5-6 the dynamic characteristics of a beam in the magnetic field calculated for magnet with circle opposite yoke (Fig. 2a) are shown. The frequencies of axial and radial motion (fig. 5) are in allowable limits.

Working point diagram along the acceleration in C200p is presented in Fig.6. 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.

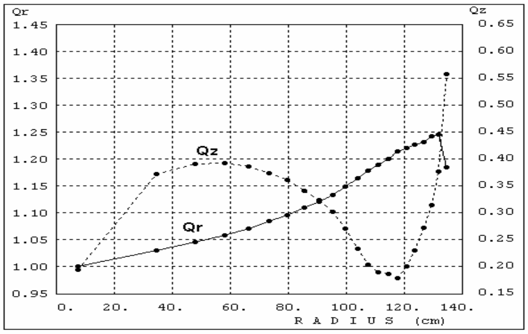

Figure 5: Betatron frequencies along radius.

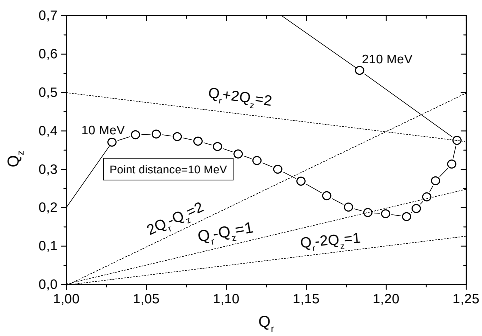

Figure 6: Working point diagram.

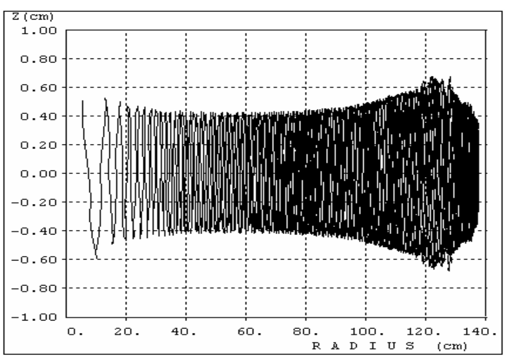

Figure 7: Axial particle motion.

Proton resonance orbital frequency is 20.4545 MHz. Axial particle motion along acceleration in magnetic field is shown in fig.7 with no skew harmonics. Amplitude of particle radial oscillation was 5 mm in 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 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 coaxial lines. The central rod located from above and from below is used for dee support. Parts of lines, which leave for the size of 400 mm are placed in channels of poles of a magnet. The basic parameters of high-frequency system are designed with three-dimensional program. For excitation of the accelerating system it is proposed to use the standard high-frequency generator on suitable capacity and frequency 81.8 MHz working on linkage feeder.

Extraction System

The extraction system consists of the beam radial enhancement system, electrostatic sections, bending and focusing magnetic elements. At the moment only central ion extraction has been calculated. To study the beam acceleration at final radii and the efficiency of the extraction it is necessary to fulfill some additional works.

Another 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 probe, one of them is on the entrance of the extraction channel. On the exit of electrostatic section of the channel the fourth short probe is arranged.

In connection with rather low required intensity of a beam in this cyclotron, it is possible to use a Pening ion source, which is moved from above in the centre of cyclotron. Extraction 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 energy of the beam E_p ~200 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.

On the basis of this project the cyclotron for the medical centers in other interested organizations can be created.

REFERENCES

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