DUBNA PROJECT OF CYCLOTRON C250 FOR PROTON THERAPY APPLICATION

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Abstract

Project of the C250 – cyclotron for proton therapy is considered. Energy of the extracted from 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, new form of HF systems of the cyclotron based on the dynamics of the proton beam in calculated magnetic and accelerating field is under discussion. Dubna scientific medicine canter is under development since 1967 on the base of the proton beam of LNP JINR Phazotron. Proton beam with energy Ep ~170 MeV and intensity I ~0.1 mkA is used for patients irradiation. Proposal of the cyclotron with the same beam characteristics was reported earlier at the RUPAC04 [1] ICAA05 [2], printed in the "Applied Physics" magazine [3], RUPAC06 [4], RUPAC08 [5].

Computer model of the double gap delta RF cavity with 2 stems was developed in a general-purpose simulation software CST STUDIO SUITE. Necessary resonant frequency and increase of the voltage along the gaps were achieved.

CACLOTRON MAGNETIC SYSTEM

In work [4] the various types of yoke are considered, is 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. On the Fig. 1 one can see the lower part of magnet system of the cyclotron C250p plane view.

The magnetic system consists of sectors, poles, horizontal and vertical yokes, current coils, the circuit of a magnet is shown on Fig. 1. In opposite valleys through 90° the high-frequency resonators are located, it one can see on the Fig. 3. The key parameters of the proton cyclotron are listed in Table 1.

The variation of a magnetic field creates four pairs flat sectors located symmetrically on poles from above and 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.

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 C250p with four symmetry return yoke (Fig. 1) is optimum and that such installation can be created as a pilot project of our institute.

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. As a material of the magnet the steel - 10 was used.

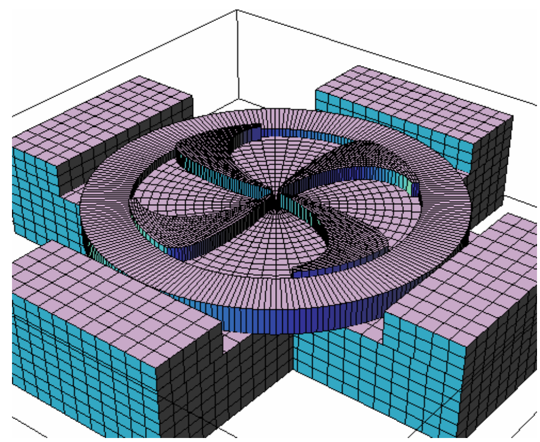

Figure 1: Magnet system of proton cyclotron C250p plane view (four symmetry return yoke).

The dynamic characteristics of beam in the magnetic field was calculated, one of them you can see on Fig. 2, all of them are in allowable limits [1, 2, 3, 4].

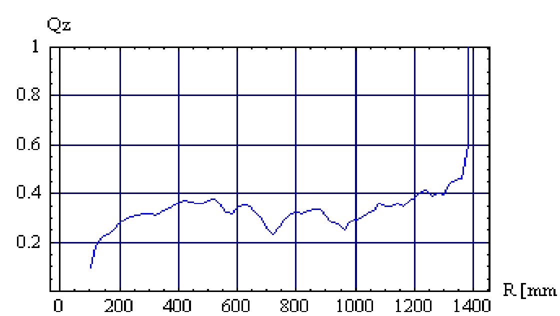

Figure 2: Dependence of frequency of axial fluctuations on radius.

Table 1: Main parameters of the cyclotron

General properties	
accelerated particles	protons
final energy of protons	250 MeV
extraction efficiency	70 % (by deflector)
number of turns	~2000
Magnetic system	
total weight	300 tons
outer diameter	7 m
height	2.8 m
pole radius	3.0 m
Valley/hill depth	20 cm/2.5cm
hill field	2.65 T
valley field	0.95T
RF system	
number of cavities	2
operating frequency	82 MHz, 4th harmonic
radial dimension	140 cm
vertical dimension	40 cm
dee voltage: center extraction	 60 kV 80 kV

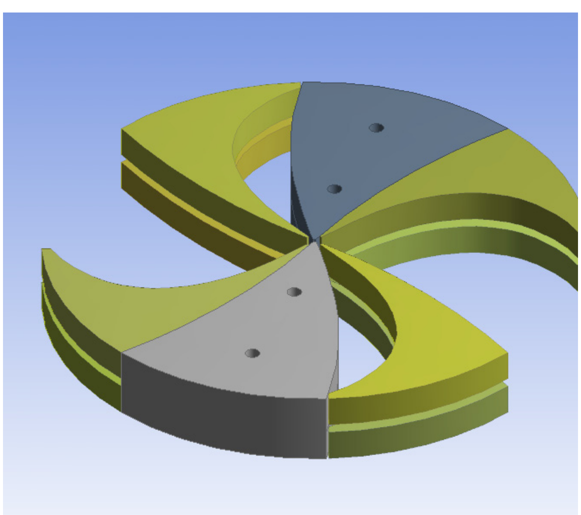

Figure 3: View of the RF-cavities in valley between of spirals.

RADIOFREQUENCY CAVITY GEOMETRY

We plan to use two RF cavities for ion beam acceleration in the C250 cyclotron (see Fig. 4). Modelling of the magnetic system and beam dynamics have determined orbital frequency of the ions equal to 20.5 MHz. As RF cavities will be operated in the 4th harmonic mode, resonance frequency must be 82 MHz.

The azimuth extension of the cavity (between the middles of the accelerating gaps) is equal to 45 deg. Cavities have a spiral shape similar to the shape of the one side of the sectors (see Fig. 3). They are located in the valleys, where the gap between poles is 400 mm. The vertical dee aperture is 40 mm. The thickness of the dee is 20 mm. The accelerating gap width is 10 mm at the center increasing to 100 mm at the extraction region. We inserted two stems with different diameter in the model. Positions of the stems determine voltage distribution along the radius of the accelerating gap. The voltage value was obtained by integrating the electric field in the median plane of the resonant cavity. For excitation of the accelerating system it is proposed to use the standard high-frequency generator on the suitable capacity and frequency 82 MHz. The active tuning system must be designed to bring the cavities to the frequency initially to compensate for detuning because of temperature variations due to RF heating.

SIMULATIONS OF THE RF CAVITY MODEL

CST STUDIO SUITE is a general-purpose simulator based on the Finite Integration Technique (FIT). This numerical method provides a universal spatial discretization scheme applicable to various electromagnetic problems ranging from static field calculations to high frequency applications in time or frequency domain. [7]. Calculations of the created model were performed using the eigenmode JD lossfree solver (Jacobi Division Method) in the CST Microwave Studio.

The computer model of the double gap delta RF cavity with 2 stems was developed, simulated and analyzed in CST Microwave Studio. The model had frequency 82 MHz and voltage value 60 – 80 kV (see Fig. 5). It was shown that the voltage behavior along the radius depends substantially on positions and diameters of the stems. The frequency value can be changed by scaling transversal dimensions of all stems without essential voltage profile modification.

Radial and azimuth electric field components and magnetic field maps in median plane were created for the beam dynamics simulation. The electric field distribution in the cavity one can see in Fig 6.

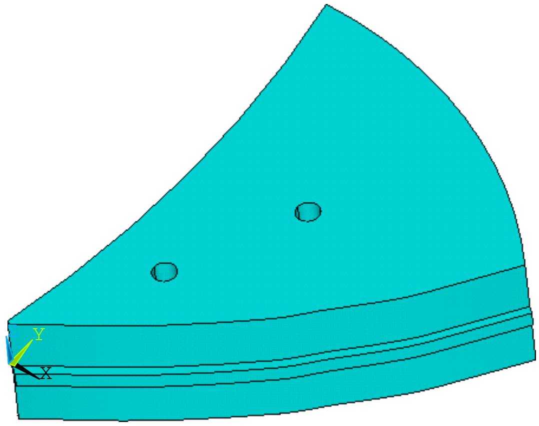

Figure 4: View of the RF cavity model.

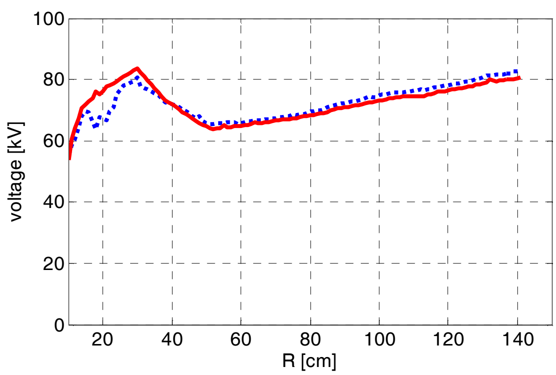

Figure 5: Voltage distribution along the radius.

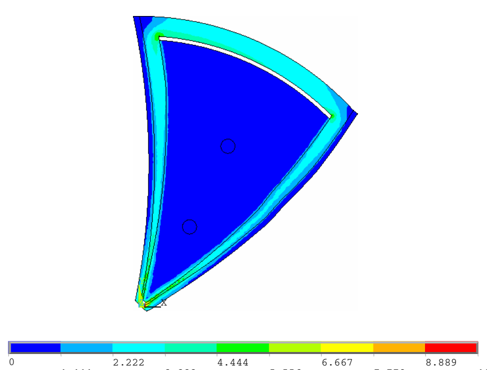

Figure 6: Electric field distribution.

CONCLUSIONS

The physical proposal 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.

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