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COMPUTER MODELING OF MAGNETIC STRUCTURE FOR IC-35 CYCLOTRON

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1. Introduction

The technical project of the IC-35 cyclotron is being elaborated at the Laboratory of Nuclear Problems of the Joint Institute for Nuclear Research. This cyclotron is designed for a wide range of radioisotope production by accelerating protons or H^- ions to 35 MeV with beam intensities 200 - 1000 μA. A conventional compact magnet with the pole diameter 1.5 m and four straight sectors was chosen for the IC-35 cyclotron. For minimizing the energy dissipated in the main magnet coil the minimal 2-cm gap between the sectors was defined, which means the use of accelerating electrodes placed in valleys between magnet sectors. The minimal valley-to-valley gap for this electrode position was estimated to be equal to 8 cm. In the case of the magnet pole diameter 1.5 m the nominal operating point was chosen as central magnetic field B_0=1.25 T and relative azimuth magnetic field variation ε=0.6-0.7. Table 1 shows the main cyclotron parameters which were used as initial ones for its magnetic system design.

Table 1: General cyclotron data

Ion beams	p, H^-
Energy	35 MeV
Revolution frequency	19.1 MHz
Average magnetic field B_0	1.25 T
Relative magnetic field variation	0.6- 0.7
Magnet pole diameter	1.5 m
Sector gap	2 cm
Valley gap	8 cm
Spiral angle	0
Number of sectors	4

2. Computer models

The well-known 2D POISCR[/1/] code was successfully used for the magnetic field calculations of some[/2-5/] rather complicated magnetic structures of cyclotrons. In these calculations two types of computer models were normally used:

- the R-φ model (azimuth symmetry mode in POISCR code);
- the X-Y model (Cartesian mode in POISCR code).

The R-φ computer model geometry for the cyclotron IC-35 magnet is shown in Figure 1. This model was used for getting data on the average magnetic field of the cyclotron. In the region of the horizontal and vertical magnet yokes their real geometry (dash line in Figure 1) in the model was converted by such a way that the cross-section in the azimuth symmetry coordinates is equal to the one of the real H - magnet. In the region of sectors the internal POISCR possibility of using the stacking factor was applied for the material data. The X-Y computer model geometry for the cyclotron IC-35 (R=50 cm) is shown in Figure 2. This model was used for getting the magnetic field variation data. The model includes a part ($\Delta\varphi$=0 - >90°) of the azimuth section of the cyclotron magnetic system at a definite set of radii (from the middle line of the sector). It includes more than one period of the system (90°). The false effective yoke is inserted into the model for passing the magnetic flux. The

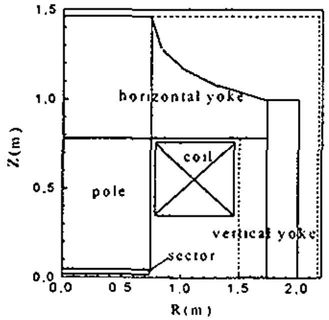

Figure 1: The view of the R-φ model for the cyclotron IC-35 magnet

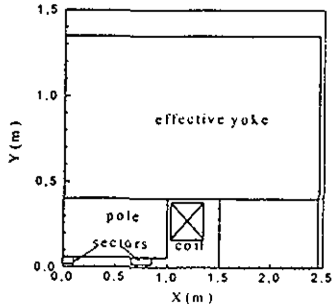

Figure 2: The view of the X-Y model for the cyclotron IC-35 magnet (R=0.5 m)

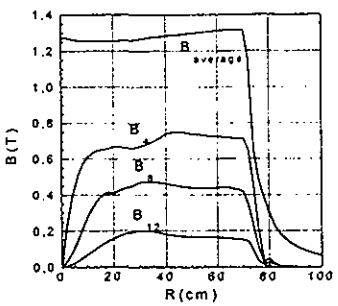

Figure 3: Magnetic field characteristics for the sector angular span α=25°

current of the coil exciting the magnetic field was chosen such that the average magnetic field equalled the required level at the radius of calculation (B=1.25-1.3 T).

3. Azimuth variation of magnetic field

The azimuth variation of the cyclotron magnetic field was calculated with the help of the X-Y model at R=5, 10, 20, 30, 40, 50, 64, 70 cm. As the sector and valley gaps were initially estimated, the calculations were performed to choose the value of the angular sector span. It was realized that for the required azimuth relative variation of the magnetic field, we need a sector span α=25° or 65°. The angular span α=25° is more suitable for the accelerating electrodes placement. The results of the Fourier analysis are presented in Figure 3 and the azimuth magnetic field distribution for R=50 cm - in Figure 4. Using the magnetic field variation data and the required average isochronous field, we calculated the frequencies of free radial and axial betatron oscilations (Q_r, Q_z). The results are presented in Figure 5.

4. Average magnetic field

The R-φ model was used to obtain data on the radial distribution of the azimuth-averaged magnetic field. The calculations were performed for the angular sector span α=25°, which means using in the computer model for the sector region of constant stacking factor equal to 0.2778. Our experience in the magnetic field calculations for the systems with straight sectors for the VINCY Cyclotron[/2/] with the help of the POISCR code showed that in the case of a low level of the average field (1-1.3 T) the computer model with constant sector stacking factor should be modified by inserting the radial variable stacking factor for compensation of the principal limitation of 2D model. The modification law for the stacking factor depends on the radius and the value of the magnetic field in the magnet gap. For getting the value of modification at each radius we did the following calculations. With the help of the X-Y model (Figure 2) we obtained the dependence of the average field on the excitation current in the coil (solid line in Figure 6). The same calculations were done for the sector region filled with the uniform magnetic material with a different stacking factor. The initial value of the stacking factor was K_{stack}=0.2778 (dash line in Figure 6). The value of the stacking factor was changed until the calculated average field dependence on the current intersects the same dependence for the sector model for the desired value of the average field ($B_{aver\,des.}$=1.3 T at R=0.5 m). For R=0.5 m it was realized at K_{stack}=0.257. Such a procedure allowed one to get the correction value for the stacking factor in the whole radial region. In the radial region $0<R<0.6R_{pole}$ the modification curve has a linear character, in the region $R>0.6R_{pole}$ a constant one. The stacking factor dependence on central magnetic field for R=0 and $0.6R_{pole}$ is presented in Figure 7. We used these curves for the central magnetic field of the IC-35 cyclotron B_0=1.25

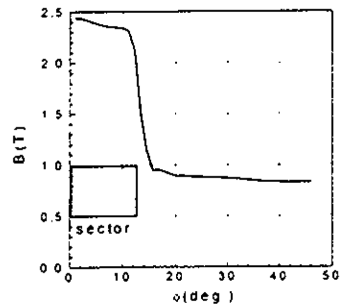

Figure 4: Azimuth magnetic field distribution for R=50 cm, α=25°

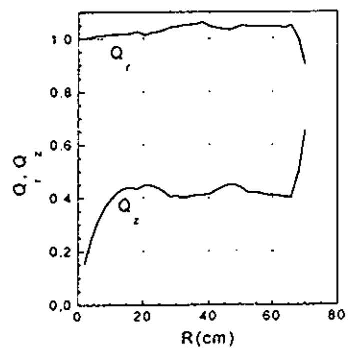

Figure 5: Frequencies of radial and axial free betatron oscillations

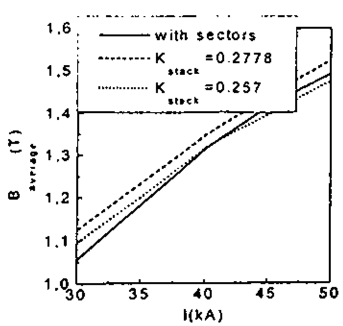

Figure 6: Average field dependence on the excitation current, R=0.5 m

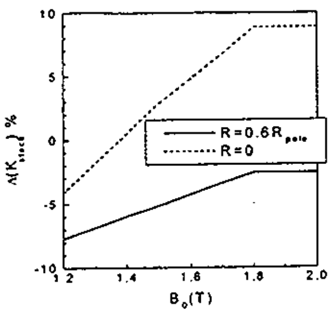

Figure 7: Relative correction of the sector stacking factor

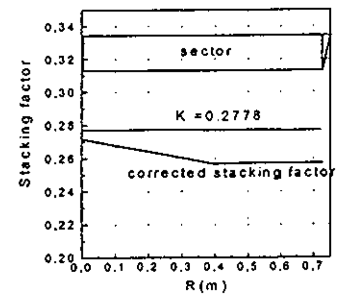

Figure 8: Radial dependence of the sector stacking factor

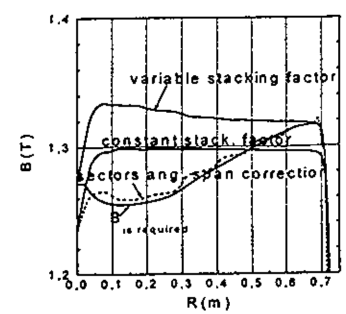

Figure 9: Radial dependence of the average magnetic field

T. The radial distribution of the variable stacking factor for the sector region is presented in Figure 8. The results of average magnetic field calculations for the constant and variable sector stacking factor can be seen in Figure 9. For getting the required isochronous magnetic field radial distribution it was necessary to insert the radial variable angular sector span in the computer model. The corrected radial dependence of the angular span is presented in Figure 10 and the shaped isochronous average magnetic field is given in Figure 9. The calculations of the average magnetic field has resulted in estimation of the main magnet parameters for the IC-35 cyclotron, which are summarized in Table 2. We chose a very low current density in the main coil conductor, which leads to a small power consumption in it. The increasing of the conductor weight will be compensated by the low cost of the main coil power supply and the absence of the main coil water cooling system.

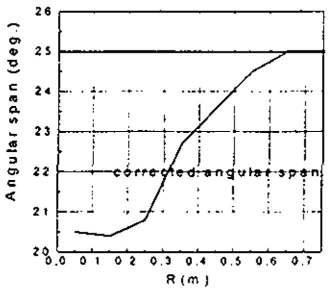

Figure 10: Radial variation of the sector angular span

Table 2: Selected parameters of the IC-35 cyclotron magnet

Diameter of pole	1.5 m
Magnet weight	120 t
Angular span of the sector	25°
Number of main coil	2
Type of conductor	Cu 18.5×18.5 mm hole ∅10 mm
Number of turns/pole	594
Main coil current for B_0=1.25 T	55 A
Current density in coil conductor	0.2 A/mm^2
Main coil weight	20 t
Main coil power consumption	≈2 kW

5. Conclusions

- Calculations by the 2D method have yielded the basic IC-35 cyclotron magnet system parameters.
- The generated magnetic field map can be used in particle dynamics calculations for choosing and optimizing the parameters of other cyclotron systems (central region, accelerating system and extraction one).

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