DESIGN AND OPTIMIZATION THE MAGNET AND MAGNETIC STRUCTURE FOR 80 MeV H^- ISOCHRONOUS CYCLOTRON

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Abstract

The design and construction of 80 MeV H^- cyclotron is being in progress at PNPI. This report is devoted to description the design of the isochronous cyclotron magnet by using the iron of the model magnet of the operating 1 GeV synchrocyclotron.

1 INTRODUCTION

The constructed cyclotron is intended both for extending the traditional for PNPI basic physics researches and for production of high quality radioisotopes for a medicine. To reduce the expenditures it was decided to use the existing in the institute infrastructure: buildings, cranes, energy supply systems, ventilation, water cooler systems. The cyclotron magnet was designed to use the iron of the model magnet of the operating 1 GeV synchrocyclotron.

The cyclotron magnetic field must meet some requirements. The magnetic rigidity on the final orbit must achieve Br = 13.2 kGs·m that corresponds to the 80 MeV energy. For isochronism it must be provided 8.5 % increasing of the azimuthal average magnetic field from center to final orbit. The azimuthal variation of the magnetic field must provide for z-focusing and permissible values of the vertical ν_z. The value of the magnetic field in the hill must be as low as possible to confine the magnetic dissociation of the H^- ions in the limit of 5 %. Allow to the room for the vacuum chamber and high frequency system the gap between sectors must be more than 140–150 mm [1].

2 MAGNET DESIGN

2.1 Selection gaps and yoke optimization

The design of the magnet and magnetic structure were done by using 2D computer code POISSON [2]. The synchrocyclotron model magnet SP-72 had the following characteristics: diameter of the cone poles was equal to 1.5 m; gap was equal to 289 mm; nominal excitation current was equal to 1.2 kA. In order to decrease the magnetic field on the final orbits at given Br the diameter of the pole has been increased up to 2 m. In such a case we have: r_f=0.9 m, $\langle B_f \rangle$ = 14.67 kGs, $B_0 = 13.52$ kGs. The base problem under the design of the cyclotron magnet is a selection the average gap, excitation current and also the hill and valley gaps. Set of the axially symmetrical magnets has been calculated with the average gaps $2g_0 = 260$, 300 and 360 mm, with the corresponding set of excitation currents and the ring shims which provided the same $\langle B(r) \rangle$ corresponding the isochronous magnetic field for 80 MeV final energy. From these calculations it was estimated that 1 cm shim thickness on the last ring corresponds to the field $\sim$ 1 kGs. The variant with average gap 300 mm and excitation current I=1200 A has been selected. That variant provides isochronous field and the minimum gap of hill ~ 150 mm and valley gap ~ 380 mm. The next step was an optimization of magnet yoke. The calculations have showed that $\sim 30\%$ increasing of the pole radius from 0.75 m to 1 m causes the increasing of the magnetic flow up to more than 1.6 of previous value and saturation the iron in the pole end. Therefore the cross section of the yoke has been increased by 16% and the height of the side pillar decreased by 0.5 m. These procedures allowed decrease the maximum field in the magnet yoke down to 23.5 kGs, decrease the excitation current down to 800 A and reduce the power consumption down to 120 kW.

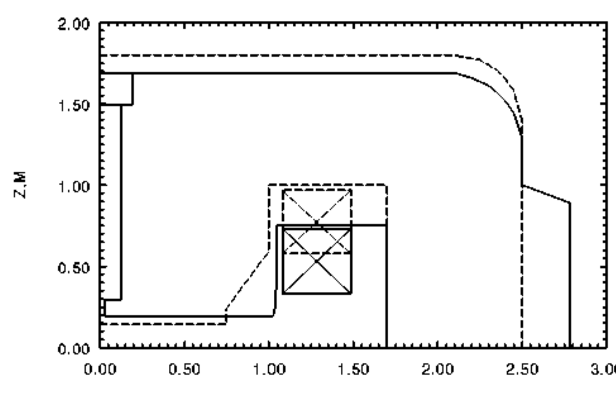

Figure 1: The reconstruction magnet SP-72 into magnet isochronous cyclotron. Dotted line is a contour of the initial magnet and solid line is a result of the reconstruction.

The dimensions of the reconstructed magnet with comparison the magnet SP-72 are shown in Fig.1.

2.2 Flutter

Flutter as a parameter having been determined by the azimuthal magnetic field distribution can not be exactly calculated by 2D program. However it is possible to make estimations if the azimuthal edge effect is represented as radial edge effect [3]. The results of the flutter estimation for the constant thickness of the hill were plotted as a function of nondimensional scale parameter $X = r\triangle\varphi/2g_H$, where r – radius, $\triangle\varphi$ – azimuthal extension of the sector and $2g_H$ – hill gap. Introduction the nondimensional scale parameter X allows to estimate the flutter decreasing under to use spiral sectors. The numerical value of the flutter decreasing can be estimated by using the same plot if instead of parameter X to substitute the effective value $X_{eff} = X cos\gamma$, where γ is a spiral angle. The spiral edge produces as well the increasing of the edge focusing as reduction of flutter. As a result the net focusing is increased on the large radii and can be decreased in the small radii. It explains the traditional using of the straight sectors in the central region.

For H^- cyclotron it is advantageous to use magnetic structure with small value of the flutter and high spiral angle to decrease the magnetic field in the hill. The magnetic structure with four sectors has been chosen. Two variants of the magnetic structure have been examined: the first with flutter F=0.04, spiral angle $\gamma = 55^0$, main harmonic amplitude of the field variation 4.14 kGs and the second–F=0.025, $\gamma = 65^0$, 3.28 kGs on the final orbits respectively.

After the detail investigation of H^- ion dissociation in the cyclotron field variant with larger spiral angle has been chosen as providing for lower magnetic field in the hill and as a consequence the smaller losses of H^- ions from the dissociation. In this case the losses of H^- ions are in limit of 5% [4].

3 MODEL MEASUREMENTS

3.1 Average field

Simultaneously with numerical calculations the model measurements for the direct investigation of the 3D effects and verification of the admitted approaches have been carried out.

At the first model with a scale $k_1 = 1.33$ we have examined the magnetic structure with comparatively low spiral angle $\gamma_1 = 55^0$. It was used SP–72 magnet like a model before reconstruction. Magnetic structure consisted of two sectors only. The central region was constructed in a complete form to the radius $r = 30$ cm. For reason of the high level dissociation H^- ions that variant of the magnetic structure was rejected. Then it was constructed a new model magnet with a scale $k_2 = 8$ and spiral angle $\gamma_2 = 65^0$. Also at the new model it was introduced the hole for the axial injection. Model variants have the same azimuthal sector extension and sector thickness, as a result we have the same dependence the average magnetic fields versus radius, as it is shown in Fig.2.

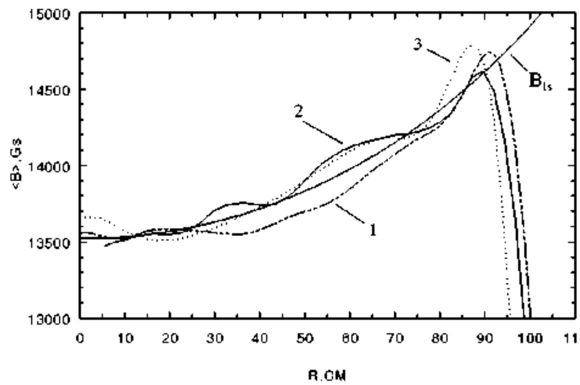

Figure 2: Average fields received for the scale models with $k_1 = 1.33$ (1) and $k_2 = 8$ (2); B_{is} – isochronous field; (3) – POISSON calculation results.

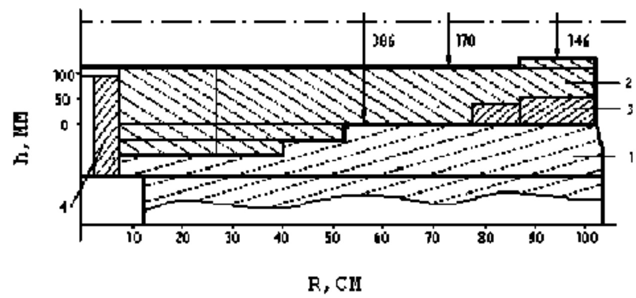

Figure 3: Shim profile in the hill and valley: 1–pole tip, 2–sector, 3–valley's shim, 4–central plug.

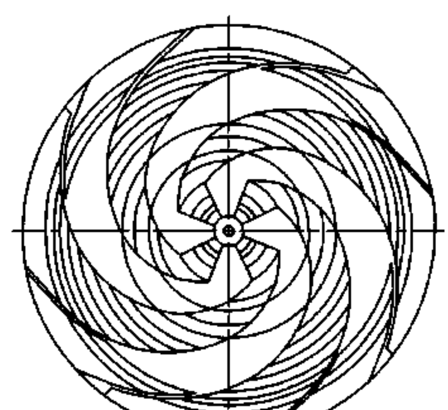

Figure 4: A plane view at the pole tip.

The profiles of the sectors and valleys are presented in Fig.3 and Fig.4. At the central region you can see a plug with diameter 150 mm, and axial hole with diameter 50 mm. We have sectors with straight edges to the radius $r = 27$ cm.

3.2 Azimuthal field variation

Axial focusing is regulated by two parameters of the magnetic field: flutter and spiral angle. In Fig.5 the final flutter data are submitted in dependence on radius according the measurements at the models and calculations. The results of the flutter measurements and calculations are in acceptable agreement.

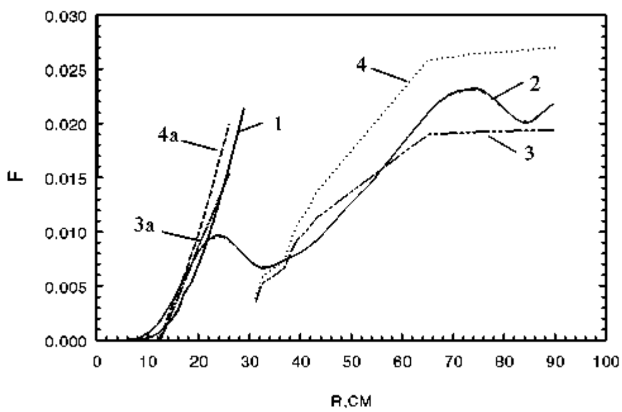

Figure 5: Flutter in dependence on cyclotron radius: 1 — the data of the measurements on model with straight sectors $k_1 = 1.33$ (central part); 2 — the data of measurements on model with $k_2 = 8$; 3 — calculations on the base of proposed methodology with $2g_V$ = 284 mm and the sector height h_1 = 69 mm; 4 — calculations with $2g_V$ = 386 mm, h_1 = 108 mm; 3a, 4a — calculations with straight sectors accordingly $2g_V$ and h_1.

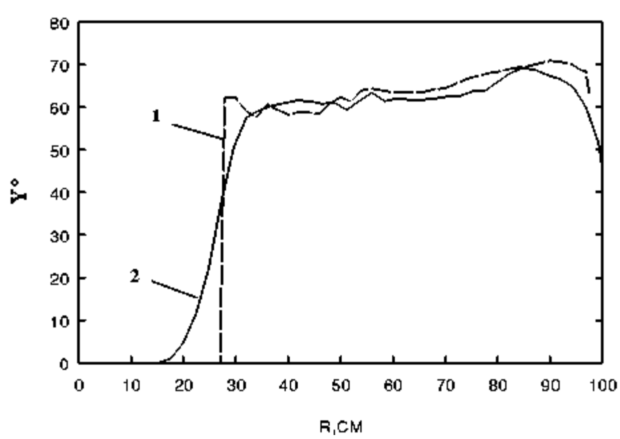

Figure 6: Spiral angle in dependence on cyclotron radius: 1 — geometry data of $k_2 = 8$ model; 2 — experimental values.

Geometrical spiral angle as well as corresponding to it magnetic spiral angle are shown in Fig.6.

The magnetic field spiral angle lags behind the geometrical one and it is the fact of special interest. At a maximum the difference between effective and geometrical spiral angles have reached approximately 4^0 that causes the reduction of focusing term at 65^0 on 30%. We obtained the analogous effect at our first model. This effect was taken into account under the magnet design.

4 CONCLUSION

The design and construction of the 80 MeV H^- isochronous cyclotron is being in progress at PNPI. To reduce the expenditure the cyclotron magnet has been designed to use the iron of the model magnet of operating 1 GeV synchrocyclotron. To decrease the average field on the final radius the pole diameter has been increased up to 2 m. In addition the magnet yoke was optimized so that the power consumption has been cut down to 120 kW.

It was used the high spiral magnetic structure with comparatively low value of the flutter by reason of the reduction the H^- losses due to electromagnetic dissociation within 5%.

The design and optimization of the magnet were done by using 2D computer code POISSON. It was developed the approximate method to calculate the flutter with spiral edge sectors.

The 3D effect and verification of the admitted approaches of the magnetic structure were investigated at two scale models.

By now the magnet of the isochronous cyclotron in Gatchina is fully manufactured including the spiral sectors and assembled. The test magnetic measurement of the excitation curve has shown that there is an agreement between the model and calculations.

5 REFERENCES

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