MAGNETIC FIELD SIMULATION IN THE CUSTOMS CYCLOTRON

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Abstract

The compact isochronous cyclotron is considered as a source of 1.747 MeV protons (H-ions) for the detection of explosives using gamma–ray resonant absorption technique.

Selection of the so called Customs Cyclotron magnetic system parameters and 3D magnetic field simulation are presented in the report. The major input parameters for selecting magnetic structure were the final H^- ion energy and the final average radius ~30cm. The beam axial size defines the minimum available axial aperture comprised by the axial air gap between the sector = 30mm. The idea was to provide the maximum axial betatron oscillation frequency > 0.5 at all radii except probably the central region. This is very important to copy with the beam space charge repulsion at the required average beam intensity ~ 5mA [1].

INRODUCTION

Selection of the cyclotron magnetic system parameters and 3D magnetic field simulation are presented.

MAGNET STRUCTURE

General view of cyclotron magnet configuration and interface with RF and extraction systems is shown in (Fig. 1).

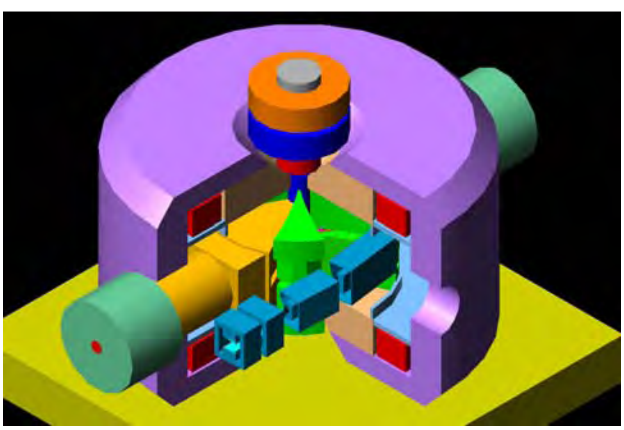

Figure 1: Magnetic structure, dees, extraction system.

Magnet cross sections is given in (Fig.2-Fig.4). Shaping of the azimuthally averaged magnetic field was performed with the help of the sector angular width variation along radius in accordance with (Fig.5).

The major input parameters for selecting magnetic structure were the final H^- ion energy = 1.747 MeV and the final average radius ~30cm. Those parameters will automatically define the central magnetic field =0.64 T and consequently the ion orbital frequency = 9.7462 MHz.

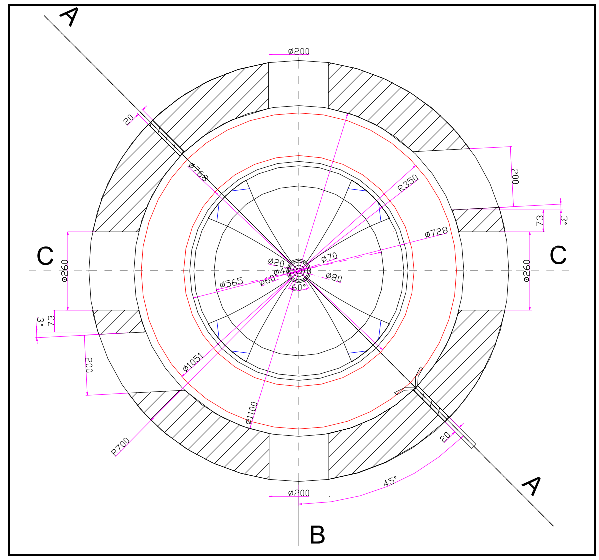

Figure 2: Magnetic system median plane layout

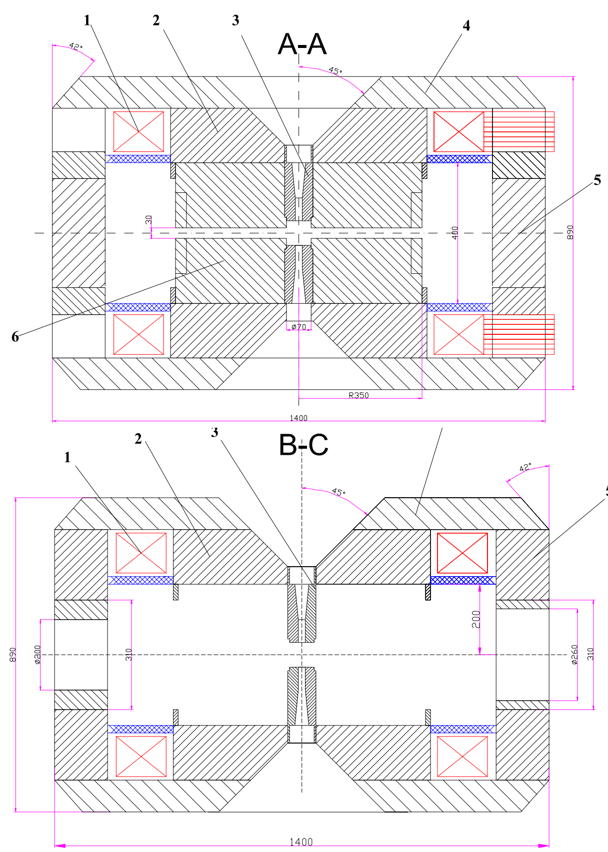

Figure 3: Magnet cross sections. 360° return yoke. Upper frame – sector symmetry plane, lower frame – valley symmetry plane. 1 – Coil, 2 – Pole, 3 – Plug, 4 – Horizontal yoke, 5 – Vertical yoke, 6 - Sector

Harmonic mode = 4 was selected to provide a maximum energy gain per turn with two ~45° dees installed in 2 opposite valleys of the 4-fold symmetry magnetic structure.

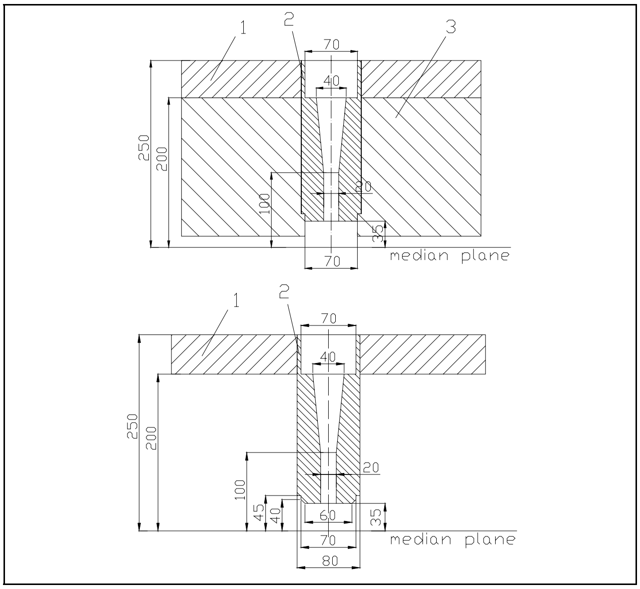

Figure 4: Central region cross-sections. Upper frame – sector symmetry plane, lower frame – valley symmetry plane. 1 – Pole, 2 – Plug, 3 - Sector

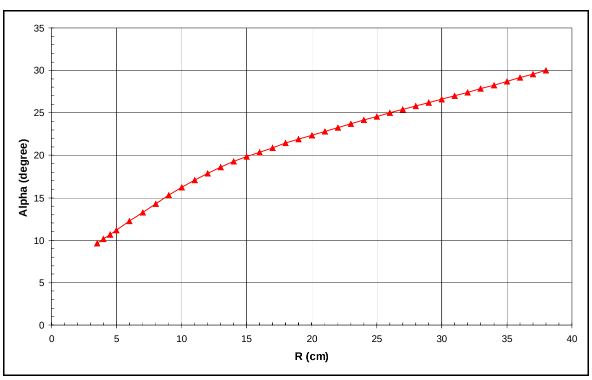

Figure 5: Sector angular width variation with radius

The beam axial size defines the minimum available axial aperture comprised by the axial air gap between the sector = 30mm. The valley gap = 400mm has been selected having in mind obtaining of the maximum possible flutter with still tolerable increase in Ampere-turns of the magnet coil for the given average magnetic field. The idea was to provide the maximum axial betatron oscillation frequency > 0.5 at all radii except probably the central region.

The final sector radius was selected to provide a good field radial range beyond the maximal radius of the final closed equilibrium orbit (EO) ~ 32cm

The coil shape and axial gap between the coils was selected taking into account the consumed magnet power and the need to release the space for the RF system.

Table 1 presents the selected system parameters defined as described above.

Table 1: Selected magnetic system parameters

Field	
Central magnetic field	0.640 T
Final average magnetic field	~0.613 T
Hill field at final radius	~1.35 T
Valley field at final radius	~0.2 T
Flutter at final radius	~0.65
Average radius of the final equilibrium orbit	~29 cm
Cyclotron radius	489.6 cm
Core	
Number of sectors/pole	4
Diameter of the pole	728 mm
Hill gap	30 mm
Valley gap	400 mm
Sector angular width	10° - 30°
Core weight	4.5 ton
Coil	
Ampere turns per magnet	58 kA*turns
Nominal coil current	362.5 A
Current density	3.2 A/ mm^2
Cu conductor dimensions	12.5×12.5×7.5 mm
Voltage	~28V
Power	~10 kW
Conductor weight	0.5 ton
Magnet	
Diameter	*1.4 m*
Height	*0.89 m*
Weight	*5 ton*

MAGNET CORE FIELD DISTRIBUTION

Magnetic field distributions in the magnet median plane (XOY) and in the cross-sections through the sector symmetry planes (ROZ) are presented in (Fig. 6-Fig. 7).

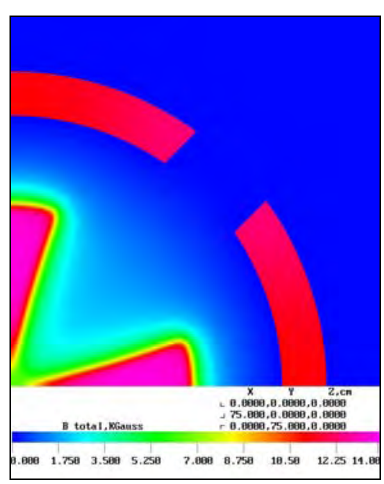

Figure 6: Midplane field map

The return yoke design reflected in the Figures showed that at the selected midplane field level the sector are highly saturated where as the magnet yoke passes through the magnetic flux without excessive Ampere-turns losses.

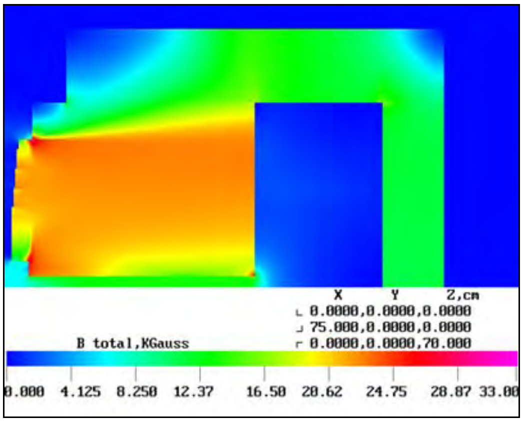

Figure 7: Magnetic field distribution in sector cross section

MIDPLANE FIELD

Isochronous Field

Azimuthal shimming of the sectors as it was mentioned above after several iterations provided the required isochronous field within the tolerances.

One of the most difficult problems to solve is the magnetic field shaping in the central region of the machine. Optimization of the central plug gap affects both the vertical sparking probability and the beam dynamics. The following limiting conditions should be met:

- Sufficient space for placement of the inflector and central region electrode structure.
- Requirements from the magnetic field measurement system.

The central region shimming was performed with the special form of the plug, shown in (Fig. 4).

Central Bump

The major problem with the beam space charge effects is related with insufficient axial focusing in the central region. The obvious method for increasing an axial focusing in the central region is introducing of falling with radius average magnetic field in such a way as to keep the RF phase only slightly changed (Fig. 8).

The attempts with calculated bump show that Q_z could be increase from 0.3 up to 0.45 at the 1^{st} orbit without essential modification of the particle RF phase. The beam acceleration simulation in the bump field performed in [2] showed that the axial focusing would not change essentially as far as the axial particle losses concerned. Nevertheless, it was decided to retain the bump field shape for future usage of its potential capability to limit the beam axial dimension applying better matching of the injected beam and having in mind minimization of some possible magnetic midplane distortions impact on the beam quality and transmission efficiency.

The result of computational shimming is shown in (Fig. 8-Fig. 9). The analysis of the dynamic properties of the field shows that the obtained map meets the requirements formulated above.[2]

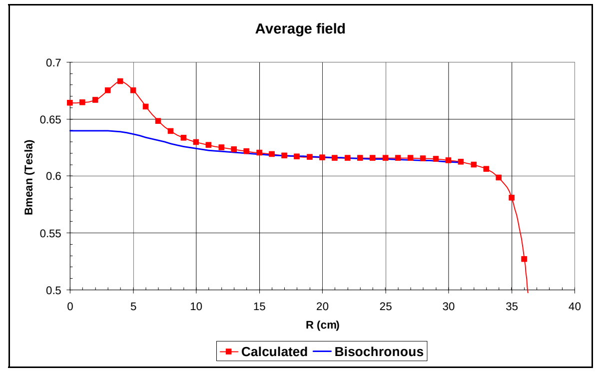

Figure 8: B-averaged with the bump

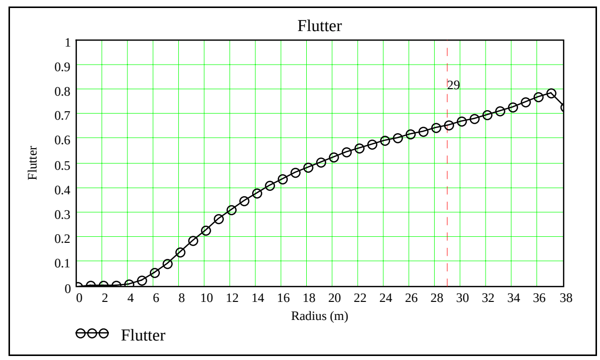

Figure 9: Flutter

CONCLUSIONS

- Magnetic structure parameters were obtained by the 3D computer simulations of the magnetic field.
- Some optimization study of the parameters selected has been performed.
- The space available for the axial injection system was released for axial injection design.
- The magnetic field maps along axial injection line, inside the cylinder comprising the spiral inflector and in the working radial range of the magnet midplane were produced for axial injection design and beam dynamics analysis.
- The obtained by simulation fringe magnetic field map was used for extraction system studies

REFERENCES

[1] V.A.Mashinin et al. Review of the Possibilities of Gamma-Resonance method of HE Detection.

[2] S.B.Vorozhtsov, E.E.Perepelkin, A.S.Vorozhtsov Dynamical Properties of the Electromagnetic Field of the Customs Cyclotron This conference.