DC-72 CYCLOTRON MAGNETIC FIELD FORMATION

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Abstract

The isochronous cyclotron DC-72 is intended to accelerate the ions from H- (A/Z=1, W=72MeV/u) up to 129Xe18+ (A/Z=7.167, W=2.7MeV/u). The cyclotron magnet has the pole of 2.6м diameter and provides the working magnetic fields at the range of 0.9T - 1.51T for the given modes of acceleration. The preliminary design of a magnetic field has been accomplished with the model of a magnet (scale 1/5) and 3D code COMPOT. The results of magnetic field final formation are presented.

INTRODUCTION

The DC-72 Cyclotron is an isochronous cyclotron with azimuthally varying field. The working diagram of the DC-72 cyclotron is presented at the figure 1. The wide diapason of the accelerated ions and their energy's sets the stringent conditions on the formation of the magnetic field distribution at the cyclotron working area.

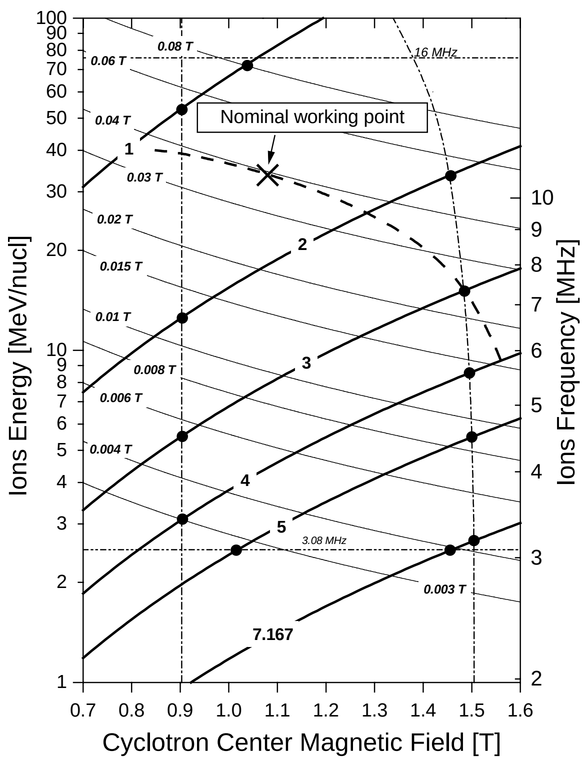

Figure 1: The working diagram of the DC-72 cyclotron.

The azimuthal variation of the magnetic field is achieved by four straight sectors per pole. The sectors have a variable axial profile at the side of the median plane of the magnet. This method of the sectors shimming give the optimal behaviour of the mean field radial growth function, dB=f(Bo) and satisfy the conditions of the working diagram [1]. At the figure 2 the area of dB(Bo) values (according to the DC72 cyclotron working diagram) and dB(Bo)-function of the cyclotron magnet (the magnetic field behaviour without using of correcting coils) are presented by the points and dash line respectively. At the figure 1 the same dB(Bo)-function of the cyclotron magnet is presented by the dash line too. The regime of Bo=1.08T and dB=400Gs were chosen as the nominal working point. The shimming of magnet structure was carried out to produce the isochronous field at this point.

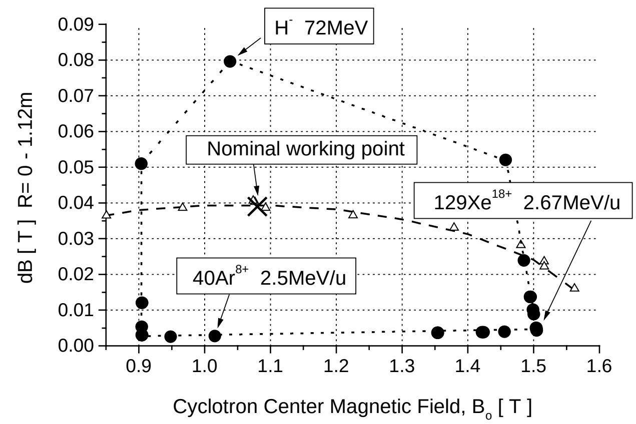

Figure 2: The working diagram area of dB(Bo) values and dB(Bo)-function of the cyclotron magnet.

Table 1: DC-72 cyclotron magnet parameters.

Magnet type	H – type
Working magnetic field diapason	0.9 – 1.52 T
Yoke length, width, height	5,6×2,7×3,1 m
Diameter of the pole	1.6 m
Gap between the poles	280mm
Minimal gap between the sectors	90mm
Gap between the pole and sector	20mm
Number of sectors per pole	4
Angular span of the sector (spirality)	45^o (0^o)
Extraction radius	1.118 m
Number of radial correcting coils	10
Number of azimuthal correcting coils	4
Maximal power consumption	70 kW
Maximal current at the main coils	340A

DC-72 CYCLOTRON MAGNET

Table 1 shows the general cyclotron magnet parameters. The peculiarity of the cyclotron magnet structure is the presence of holes for resonators, vacuum pumping and power supply wires of correcting coils. These holes are placed at each "valley" and distort the magnetic field. The effect of the valley holes is considered at the form of required isochronous fields. Ten pairs of the radial correcting coils gives necessary freedom for selection the dB(Bo) function value according working diagram. They are located in the space between the sectors and the pole and provide the additional correction of the working magnetic field to obtain the isochronous distribution for the given modes of acceleration. Four pairs of the azimuthal correcting coils provide the operative correction of the beam orbit centering, see figure 3. Both radial and azimuthal correcting coils have a 40 turns per pole and maximum current 35A.

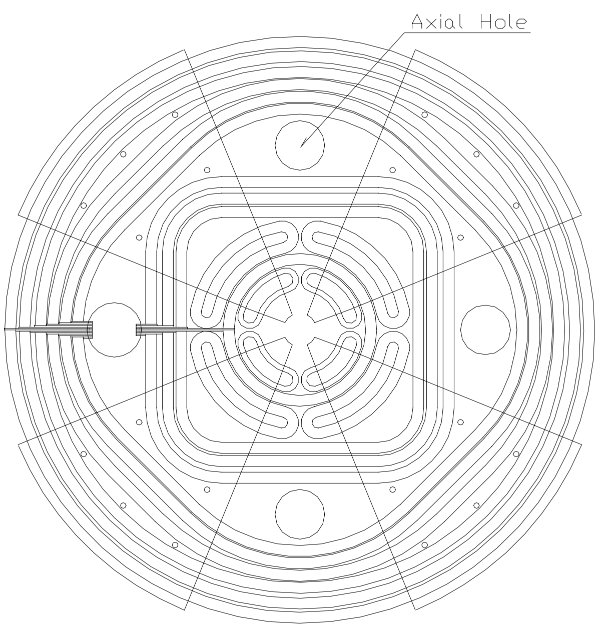

Figure 3: The position of the ten radial and four azimuthal correcting coils on the magnet pole.

MAGNETIC FIELD COMPUTATION AND MODELING

The preliminary researches of the magnetic field behaviour for the given modes of acceleration are conducted on the model of the DC-72 cyclotron magnet, scale 1/5. The research of the different methods of the sector shimming has been carried out on this model. The method of the "top" axial shimming (the sectors are processed at the side of the median plane of the magnet) was chosen as the main one [1]. Simultaneously, the magnetic field simulation was performed with the help of 3-D computer code KOMPOT [2]. The measured magnetic characteristics of the magnet yoke elements were taken into account at the calculation. The actual axial profile of the sectors as a result of modelling and computation are presented at the figure 4.

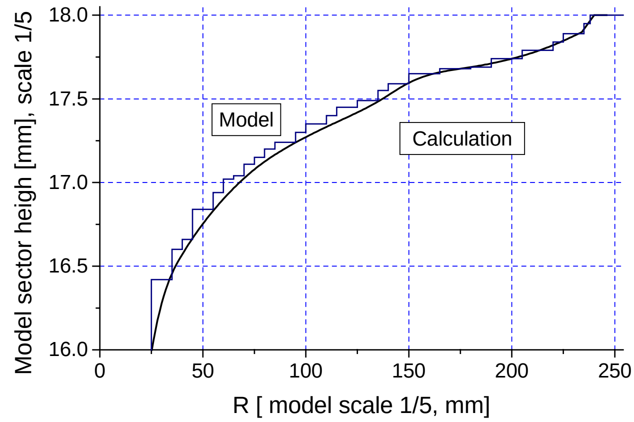

Figure 4: Sector axial profile, scale 1/5, from the modelling and the computation.

FORMATION OF CYCLOTRON MAGNETIC FIELD

The DC-72 cyclotron magnet was manufactured based on the results of modelling and calculation. To produce the "thin" correction of the magnetic field at the nominal working point the 10mm azimutal wide plates are placed at the both sides of each sector. The axial processing of these plates allows correcting the magnetic field first harmonic and the local unlinearity of the field radial behaviour. The measuring of the magnetic field distribution at the median plane was carried out by the unique measured system. The magnetometer has 8 Hall probes placed with a radial distance 200mm. The radial measured distance is 0 ÷ 1600mm with 10mm or 20mm steps. There are azimuthal measured regimes of 90^o and 360^o with 1^o or 2^o steps. Formation of cyclotron magnetic field was carried out at 3 stages. First stage was a magnetic field first harmonic correction. The result of this correction is presented at the figure 5.

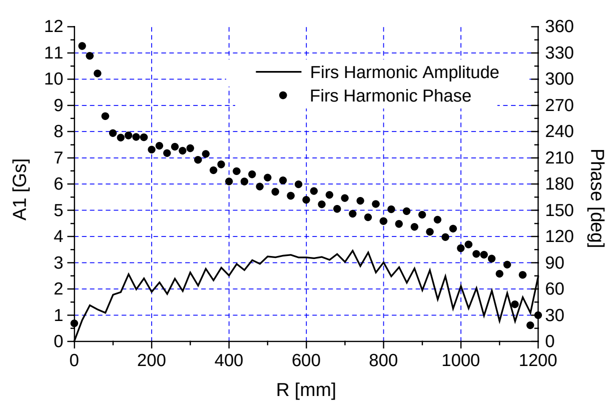

Figure 5: First harmonic amplitude and phase after correction.

At the second stage the formation of the field at the nominal working point was carried out. The form of this field must be suitable for the subsequent formation with the radial correcting coils the most important regime H- (72MeV). At the figure 6 the measured nominal working point field is presented. At the same figure the regimes of H- (72MeV) and 40Ar+5 (3.2MeV) are presented by the calculated isochronous fields and fields, formed with correcting coils (simulation version).

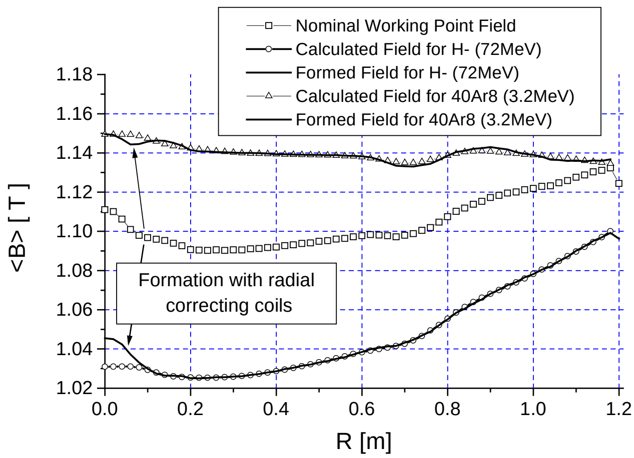

Figure 6: Formation of isochronous field for H- (72Mev) and 40Ar+5 (3.2 MeV) regimes by means of radial correcting coils.

At the third stage the contributions of radial and azimuthal correcting coils fields were measured at 7 levels of main magnetic fields.

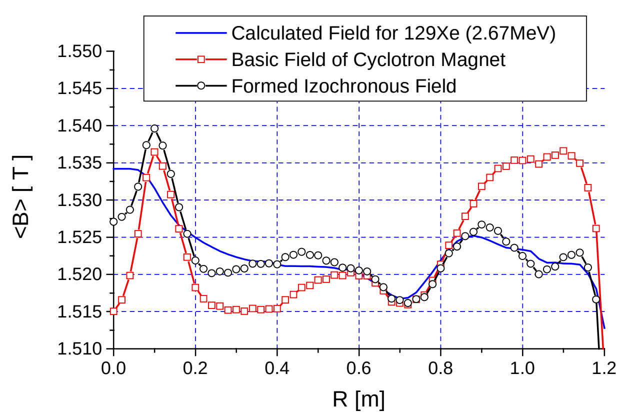

Figure 7: Formation of isochronous field for 129Xe+18 (2.67Mev) regime by means of radial correcting coils.

The forms of contribution of radial coils are different when they are turned on positively or negatively regarding to the main magnet field. The smaller the levels of main field the more this difference. For the correct formation of isochronous field for H- (72Mev) one have had to measure both positive and negative radial coils contributions. At the higher-level magnetic field, 1.5T, the positive and negative contributions are practically identical. At the figure 8 the positive contribution of 10 radial coils at 1.1T main field are presented. The coils current is 35A. Based on the measured magnetic fields of main magnet and correcting coils the main regimes of cyclotron working diagram (H- (72MeV), 129 Xe+18 (2.67MeV), at all.) were calculated and then measured, figures 6 and 7.

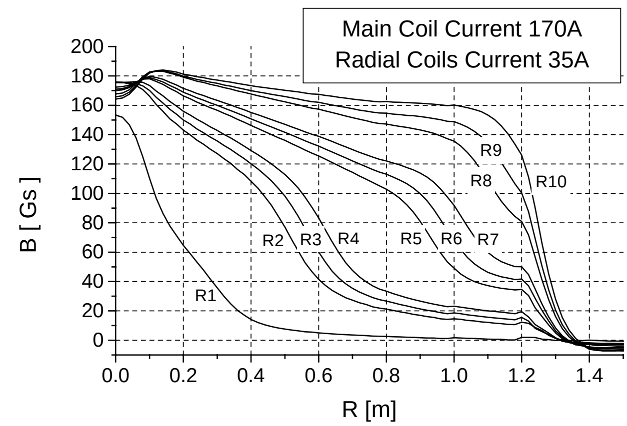

Figure 8: Fields of the ten radial correcting coils.

CONCLUSION

The formation of DC-72 cyclotron magnetic field was carried out. The modelling and 3D computer simulations of the magnet elements were used for preliminary choice of the cyclotron magnet structure. For exact isochronous magnetic field forming at the nominal working point and correction of the field first harmonic the side sectors shims were used. The measured magnetic fields of main magnet and correcting coils at the different levels are used at the computer program to forming any regimes of the working diagram. The following calculations of the beam dynamics at the chosen working regimes with the appropriate magnetic fields, formed with correcting coils and then measured, show the satisfying results.

REFERENCES

[1] I. Ivanenko, G. Gulbekian, J. Franko, A. Semchenkov, “The model of DC72 cyclotron magnet. The research of the sector shimming methods for obtaining the working magnetic field for light and heavy ions acceleration,” EPAC2002.

[2] G. Gulbekian and all., “A method of the magnetic field formation in cyclotron DC-72,” NUKLEONIKA, Vol. 48, number 4 - 2003, pp. 207-210.