# 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.

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*Abstract*

The model of DC72 cyclotron magnet (scale 1/5) is intended for simulation of the cyclotron magnetic structure. The magnetic field behaviour should provide the acceleration of the ions from H- to $^{129}Xe^{18+}$. The behavior of the cyclotron magnetic field at the different methods of the magnetic structure shimming and the different levels of the magnet excitation has been investigated. The results of this investigation are presented.

## 1 INTRODUCTION

At the moment, the activities on creation of the isochronous cyclotron DC-72 for the cyclotron complex of Slovakia are carried out at the FLNR, JINR [1]. The isochronous cyclotron DC-72 is intended for obtaining the beams of the accelerated ions from H-:(A/Z=1, W=72MeV/u) up to $^{129}Xe^{18+}$:(A/Z=7.167, W=2.672MeV/u). The magnet of the cyclotron has the pole diameter size of 2.6m and provides the working magnetic fields in the range from 0.9T to 1.51T for the given modes of acceleration.

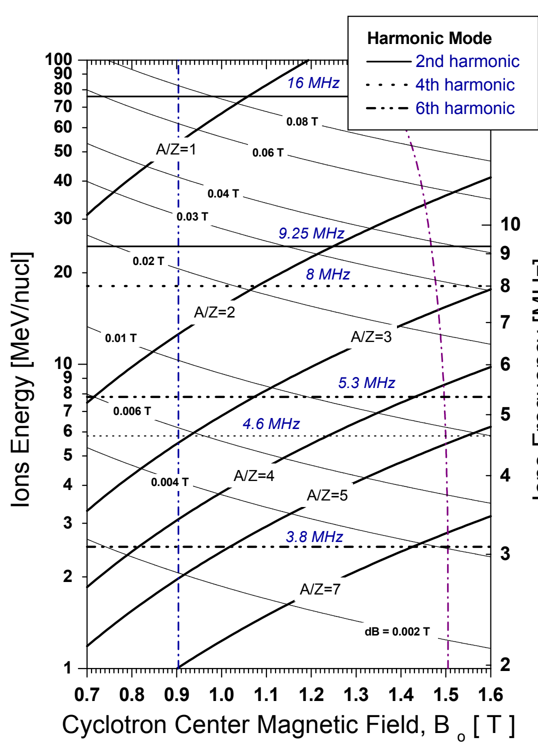


Figure 1: The working diagram of the DC-72 isochronous cyclotron.

The relation of the distance in the "valley" (between poles) to the distance in the"hill" (between sectors) is equal $d_{valley} / d_{hill} = 2.8$. Four pairs of straight-line sectors with an angular expansion of 45 degrees shape the working magnetic field. Ten pairs of the radial correcting coils provide the additional correction of the working magnetic field to obtain the isochronous distribution for the given modes of acceleration. The broad diapason of the accelerated ions presented at the working diagram (figure 1) sets the stringent conditions on the formation of the magnetic field distribution at the cyclotron working area. The behavior of the growth function of the radial mean field, dB=f (Bo), is the important criterion of the designing of the cyclotron magnetic structure. The value dB is determined as the difference $Br_{out} - Bo$, where $Br_{out}$ is an average magnetic field at the extraction radius, and Bo is an magnetic field at the cyclotron center. At the figure 2 the area of the position of the function dB=f (Bo) (according to the DC72 cyclotron working diagram) is surrounded by points. These points present some important cyclotron acceleration modes. The usage of the radial correcting coils gives some freedom for selection the dB (Bo) function form. At the figure 2 the value Bo =1.038T is the most important point. This point refers to both acceleration modes of the ions H-: A/Z=1, W=72MeV/u, dB≈800Gs and $^{40}Ar^{8+}$: A/Z=6.6, W=2.5MeV/u, dB≈28Gs. The total contribution of the coils to the magnetic field (about ±450Gs) was chosen to cover the range of dB from 28Gs to 800Gs.

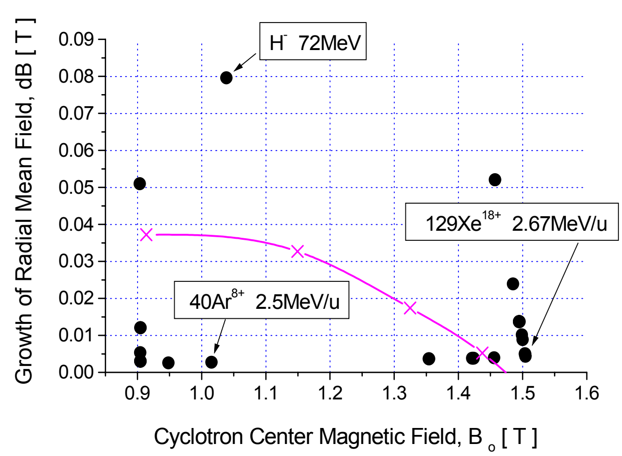


Figure 2: The dependence of the growth function of the radial mean field ($dB = Br_{out} - Bo$) on the field Bo in the center of the cyclotron.

## 2 MAGNET MODEL

The preliminary researches of the magnetic field behavior for the given modes of acceleration are conducted on the model of the DC-72 cyclotron magnet. The main dimensions of the magnet model correspond to the sizes of the "real" magnet with the factor of scaling 1:5. The design of the model allows making a fast replacement and adaptation of the magnetic structure units at the working area. The measurements of the magnetic field distribution in the median plane of the working area are implemented by the specially constructed magnetometer. The mechanical part of the magnetometer consists of a thin bar. Four Hall probes are located on this bar. The pneumo and electrical drivers provide the radial and azimuthal movements of the bar. The computer implements the control of the magnetometer bar movement and the data handling automatically. The azimuthal movement of the bar is 90 or 180 degrees with the step of 2 degrees. At the radial direction the bar displaces from the centre up to the area of the fringe fields behind the magnet pole with the step of 4 millimetres. The magnetometer allows to receive the distributions of the magnetic field with accuracy about $10^{-3}$. The total measuring time for 90-degrees mode is about an hour and 15 minutes.

## 3 METHODS OF THE SECTOR SHIMMING

The axial or (and) azimuthal shimming of the sectors forms the requisite magnetic field distribution. The purpose of the work presented here is to find the reasonable method of the shimming of the sectors to satisfy the working diagram conditions. The different methods of the shimming are considered below.

### *3.1 Dependence of the dB(Bo) function behavior on the method of the sector shimming*

The satisfaction of the given conditions, introduced at the figures 1 and 2, is the main criterion of selection of the sectors shimming method. In this paper three methods of the sectors shimming are considered:

- The method of the azimuthal shimming of the sectors. At this method the sectors were processed azimuthally.
- The method of the "bottom" axial shimming of the sectors. At this method the sectors were processed at the side of the magnet pole.
- The method of the "top" axial shimming of the sectors. At this method the sectors were processed at the side of the working area of the magnet.

The functions dB (Bo) for the submitted methods of the sector shimming are shown at the figure 3. The functions "bottom A" and "bottom B" are obtained at the same "bottom" axial shimming method, but differ in the depth of the sector surface processing.

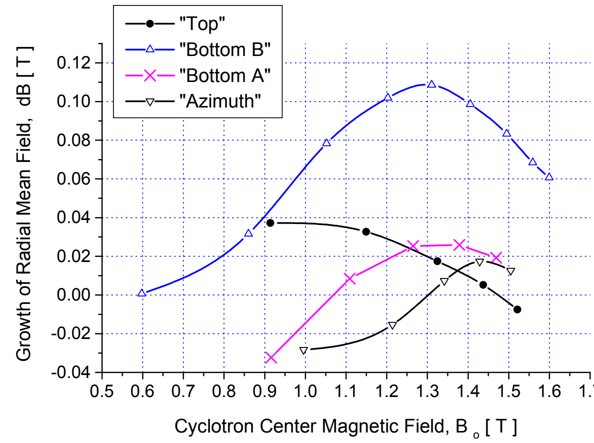


Figure 3: The dependence of the growth function of the radial mean field ($dB = B_{rout} - Bo$) on the field Bo in the center of the cyclotron.

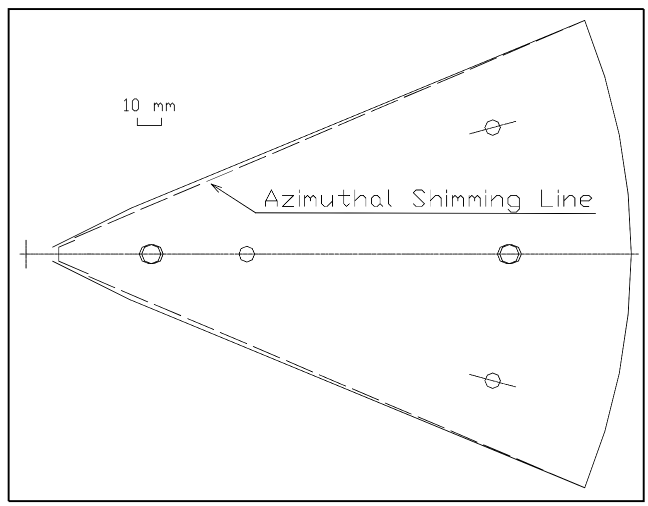


Figure 4: The considered profile of the sector azimuthal processing.

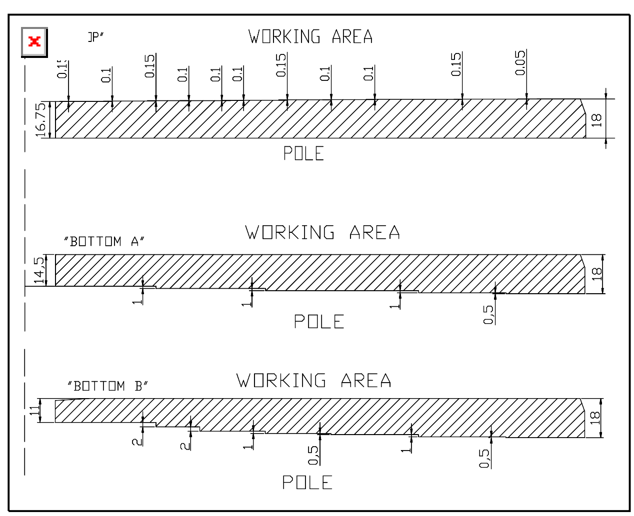


Figure 5: "Top" and "bottom A, B" profiles of the sector surface processing.

The considered profile of the sector azimuthal processing is shown at the figure 4. The "top" and the "bottom A, B" profiles of the sector surface processing are shown at the figure 5. The result of comparison of the figures 2 and 3 gives the choice of the "top" axial shimming method. The azimuthal and "bottom" axial shimming methods are unsatisfied for the conditions of the working diagram. At the figure 2 the behaviour of the function dB=f (Bo) of the "top" axial shimming method is presented by line.

### *3.2 Sensitivity of the considered methods of the sector axial shimming*

The dependence of the magnetic field sensitivity on the methods of the sector axial shimming was researched. At the figure 6 the differences of the mean magnetic fields $\Delta B = \langle B_{flat} \rangle - \langle B_{shimm} \rangle$ for "bottom A" and "top" shimming methods are submitted. $\langle B_{flat} \rangle$ is the mean magnetic field obtained with the flat, unshimming sectors. $\langle B_{shimm} \rangle$ is the mean magnetic field obtained with the axial shimming sectors.

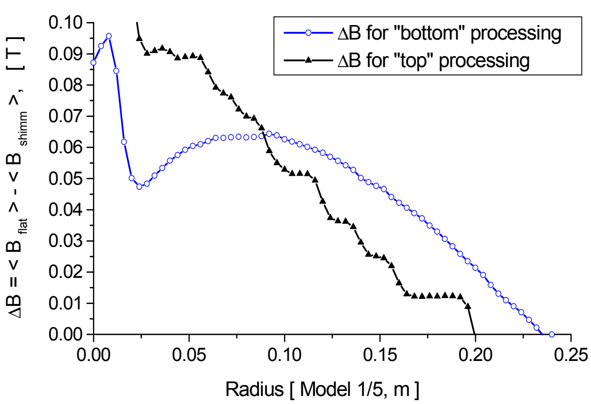


Figure 6: The differences of the mean magnetic fields for the flat and axial processed sector surfaces (the "bottom A" and "top" methods).

The comparison of the "bottom A" and "top" profiles (figure 5) and the corresponding magnetic field contributions (figure 6) gives the following conclusions:

- The influence of the stepwise form in the case of the processing of the sector "bottom" surface is insignificant. In spite of the appreciable height of the steps (0.5÷1 mm for the model and 2.5÷5 mm for the "real" magnet), the contribution of ΔB is rather smooth.
- On the other side, the stepwise form in the case of the processing of the sector "top" surface produces the wave of the mean magnetic field along the radius. In the case of the 1/5 magnet model the height of the step 50mkm produces the wave with the amplitude about 15÷20 Gs.
- In the case of the sector axial shimming at the side of the poles the sensitivity is about 3 times lower than in the case of the sector axial shimming at the side of the working area.

## 4 CONCLUSION

The purpose of the work is to obtain the reasonable form of the dB (Bo) function to satisfy the working diagram conditions. The research of the different methods of the sector shimming has been carried out. The method of the "top" axial shimming (the sectors are processed at the side of the magnet working area) was chosen as the main one. The method of the azimuthal shimming will be used for the fine correction of the isochronous distribution of the magnetic field.

## 5 REFERENCES

[1] http://159.93.28.88/cap/dc-72.html

[2] G.G. Gulbekian, J. Franko "Algorithm of synthesis and analysis of magnetic structure characteristics of isochronous cyclotrons with cylindrical poles", P9-92-129, JINR Preprint, Dubna, 1992.