SIMULATION OF THE VINCY CYCLOTRON MAGNETIC FIELD USING A MODEL MAGNET

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Abstract

This paper presents the results of magnetic field measurements on a model magnet suited for simulation of the VINCY Cyclotron magnet on the scale 1:10. Ten sets of sectors and twelve pairs of plugs have been considered in order to study various effects. The results that have been obtained form a valuable experimental basis for the design of the real magnet.

1 INTRODUCTION

The main part of the TESLA Accelerator Installation is the VINCY Cyclotron [1,2]. It is an azimuthally varying field cyclotron designed to accelerate ions in a wide range of specific charges.

To get accurate design parameters, the magnetic field computations [3,4] were coupled with measurements on the model magnet of the Flerov Laboratory of Nuclear Reactions, Dubna. As shown in Table 1, most parameters of the model are well suited to the real magnet in the scale 1:10. There are some differences in the yokes and main coils, but they are less important when the median plane field is considered.

Table 1: Comparison of the model magnet and the VINCY Cyclotron magnet

Parameter	Model magnet	VINCY Cyclotron
Pole diameter	200.0 mm	2000 mm
Angular span of the sectors	42°	42°
Hill to hill gap	3.1 mm	31 mm
Valley to valley gap	19.0 mm	190 mm
Yoke width	200.0 mm	2000 mm
Yoke length	445.0 mm	4120 mm
Pole height	82.4 mm	690 mm
Pillar height	183.8 mm	1570 mm
Distance between the pillars	340.0 mm	3120 mm
Distance between main coils	59.8 mm	706 mm
Number of main coil turns	2 x 36	2 x 256
Maximum main coil current	650 A	1000 A

2 MEASUREMENT PROCEDURE

The measurement equipment consists of a Hall probe mounted on a straight ruler which can rotate around the magnet axis. By moving the ruler radially and azimuthally the probe can cover the region of one whole sector and two halves of two neighbor valleys.

In most cases, a radial step of 5 mm and azimuthal step of 2° were used. This yields a field map of 21x46=966 points. To get field details in the central region (0-20 mm), the radial step was decreased to 3 mm. The same step was used to measure the stray field in the extraction region (85-110 mm).

The Hall probe has been calibrated against the NMR Teslameter. However, the measurement inaccuracy was rather high, of the order of magnitude ±0.5%, due both to the probe dimensions and hand-driven ruler. Data processing has been performed by the BCAL program package [5].

To get an insight into various effects, as well as to check and adjust the computational methods, a large series of measurements has been carried out by varying the following magnet parameters:

- Sector material (Steel-10 and ARMCO)
- Sector thickness (0, 6.45, 6.60 and 7.95 mm)
- Shape of the sector end (vertical and Rogowsky)
- Sector profile (axial and azimuthal shim)
- Plug gap (3.4, 5.3 and 9.3 mm)
- Diameter of plug hole (1, 2 and 3 mm)
- Plug shape (spacer, sector facet , Rogowsky shape in the valley region etc.)
- Main coil current (nominal and two extreme currents, 470, 178 and 650 A, respectively)

To reduce the number of possible combinations, the measurements were performed in a number of steps. After each step, the 2D computer models [3] were adjusted by introducing a variable stacking factor according to experimental data. The general parameters, such as the sector thickness, and sector material, have been considered first. The further steps were dealing with the sector shim and the plug shaping.

3 RESULTS

The nominal operating point of the VINCY Cyclotron is designed for acceleration of D^- ions up to 30 MeV per nucleon. According to calculations, the corresponding magnetic field can be obtained by the main coil current of 661 A (470 A for the model magnet). The main goal of simulation was to achieve this field by means of iron. It was done, within the measurement accuracy, by two different (axial and azimuthal) sector shims.

3.1 Axial shim

The preliminary design of the VINCY Cyclotron was based on axial reduction (shim) of the sector thickness along the radius. The necessary sector profile was obtained by 2D calculations in three iterations as shown in Figure 1.

The first iteration was based on the standard POISCR [6] calculations. In the second iteration, 3D results of a simplified model of the VINCY Cyclotron [3] have been

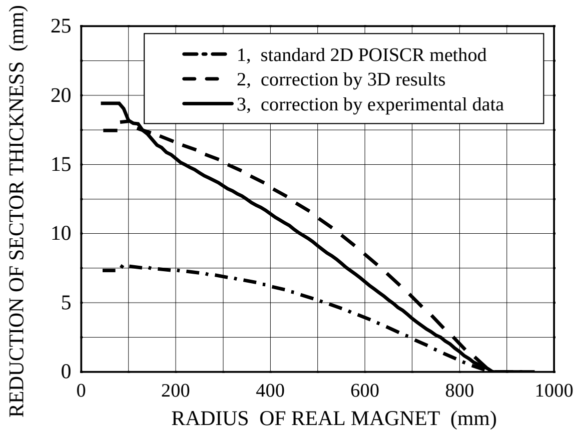

Figure 1. Three iterations in computation of the axial sector profile of the real magnet

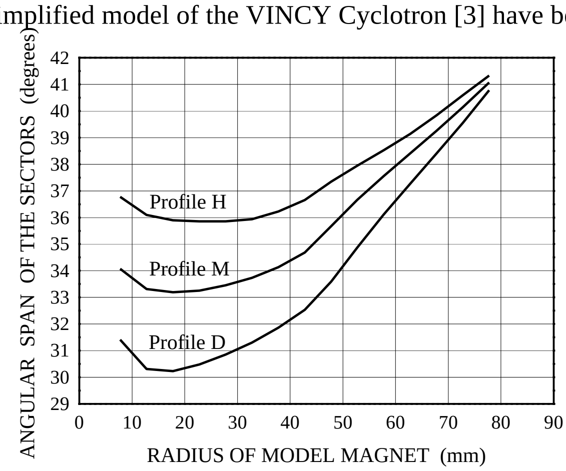

Figure 3. Azimuthal sector profiles

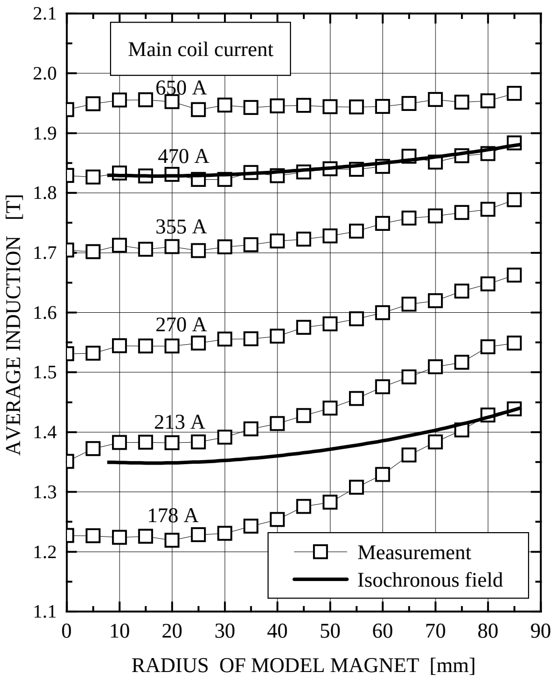

Figure 2. Radial distribution of average magnetic field for the third iteration of axial profile

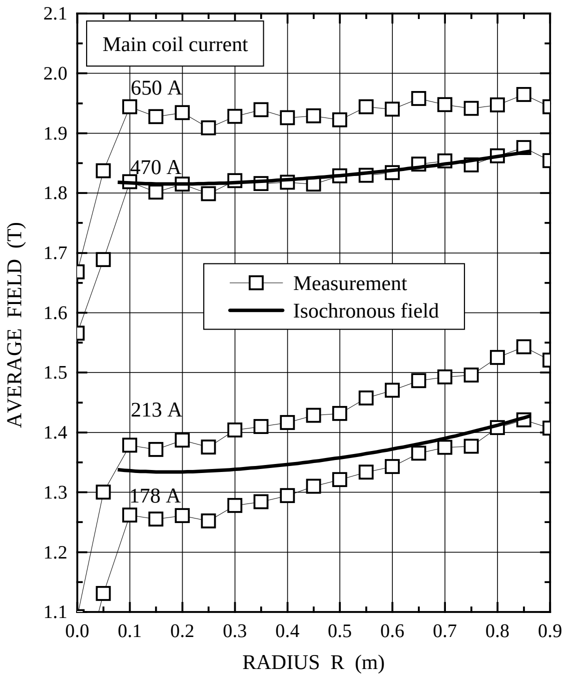

Figure 4. Radial distribution of average magnetic field in the case of azimuthal shimming

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used to correct the computing method. However, the measurements have shown a discrepancy of ±25 mT. It is mainly due to the sector end effects that have been neglected in the simplified 3D model. In the third iteration the computing method was corrected by the experimental data of the previous sector profile. Figure 2 compares these results with the isochronous field for two characteristic values of the main coil current. A large deviation (125 mT) can be observed between the actual and isochronous field for low level magnet excitation.

3.2 Azimuthal shim

In this case the angular span of the sectors is decreased radially while the sector thickness is kept constant. Three profiles (Figure 3) have been used to approach to the nominal isochronous field. The final results are presented in Figure 4

Comparing the Figures 2 and 4, one can notice that the dispersion of the results is slightly higher in the latter case. This is caused by different sector machining. The axial shim has been produced on a CNC machine with an accuracy of few tenths of millimeter. Contrary to that, a stepwise profile with a rather large step (5 mm) has been used in the case of azimuthal shim.

Concerning the low level magnet excitation, it is easy to see that the azimuthal shim yields to a twice smaller deviation (75 mT) than the axial one. This means that the operating range of the real magnet can be much larger if azimuthal shim is applied. In that case, however, a serious disadvantage is the design of the magnetic plug in the center of the machine. To resolve this problem, the effect of plug shape has been studied in the further measurements.

3.3 Plug shaping

The role of the plug is to release enough space both for the inflector and the electrodes in the central region. At the same time it has to produce a field bump in the very center. It is hard to do that when the gap between the sectors is narrow as in the case of azimuthal shimming. Therefore, an extensive series of measurements has been carried out with various plug shapes. The plug shape presented in Figure 5 satisfies the above requirements as shown in Figure 6.

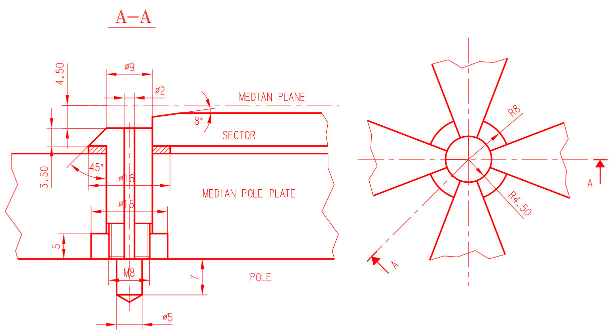

Figure 5. Final shape of the magnetic plug

4 CONCLUSION

This paper presents only a small portion of experimental data that have been obtained. More than hundred measurements have been carried out on the model magnet. These results form a valuable basis for the final design of the VINCY Cyclotron magnet as presented in the companion paper [7].

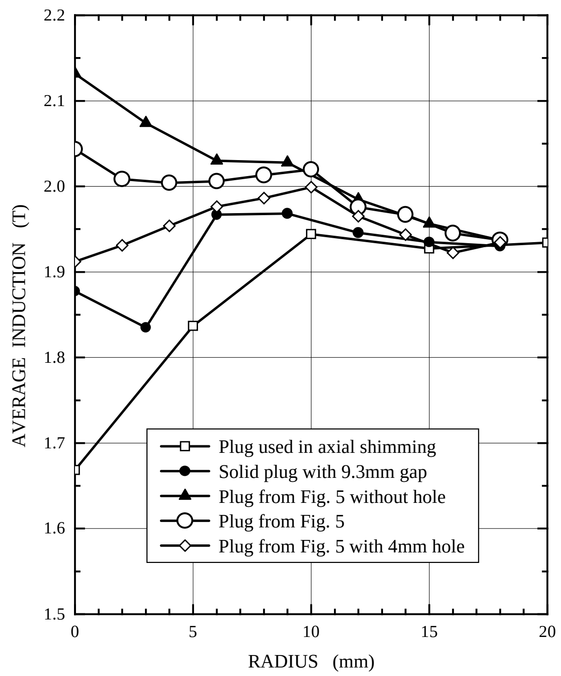

Figure 6. Radial distribution of average magnetic field for the plug shape from Figure 5

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