OPERATING RANGE OF THE VINCY CYCLOTRON

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Abstract

An extensive series of calculations and model magnet measurements has been carried out in order to design the magnetic structure of the VINCY Cyclotron. This paper presents the most characteristic data of the magnet design and the operating range of the machine that is expected.

1 INTRODUCTION

The construction of the VINCY Cyclotron [1,2] is going on in the VINCA Institute of Nuclear Sciences, in Belgrade, Yugoslavia. It is designed as a multipurpose machine able to yield a wide range of ion beams for a variety of applications. To illustrate the requirements that have been imposed on the cyclotron design, a set of ion beams is listed in Table 1 according to the user programs proposed at this stage.

Table 1: Selected set of expected ion beams from the VINCY Cyclotron

Ion beam	**Energy** (MeV/nucl)	**Application**
H^-	66	Proton therapy
H_2^+, D^-	21-35	Radioisotope production
H_3^+	15	Radioisotope production
O^{4+}, O^{5+}	4-10	Heavy ion nuclear reactions
$Ne^{4+} - Ne^{10+}$	3-30	Physics of thin crystals
Xe^{20+}	3	Radiation Physics Radiolysis in cond. systems Biological effects

2 MAGNETIC STRUCTURE

The magnet of the VINCY Cyclotron is a conventional compact magnet with pole diameter of 2 m. It has two main coils that are wound from a rectangular hollow oxygen free high conductivity copper conductor. The total number of windings is 512 and the maximum current is 1000 A.

The azimuthal variation of magnetic field is achieved by four straight sectors per pole. The angular span of the sectors is 42°, the maximum thickness is 66 mm, and the minimum gap is 31 mm. The median pole plates are flat and the distance between them is 190 mm. The Rogowsky shape is applied both to the sectors and the pole in order to focus the magnetic field in the region of extraction (R_{ext}= 860 mm).

The ferromagnetic elements are made from three kinds of ARMCO type iron. Figure 1 shows the related B(H) curves that have been measured in the Laboratory of Nuclear Problems, JINR, Dubna.

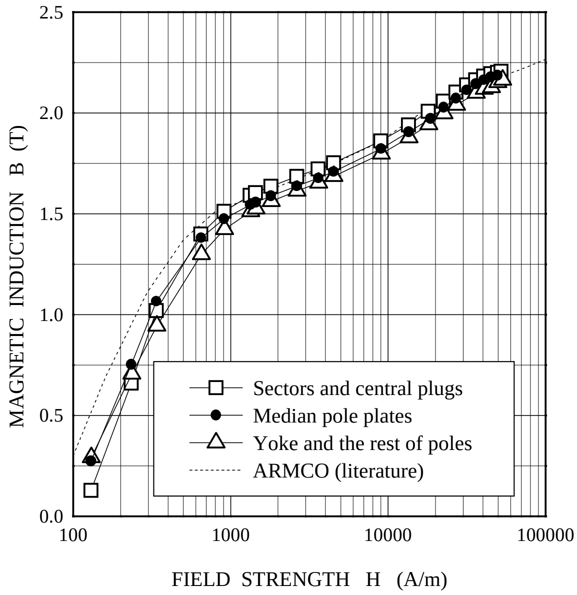

Figure 1. Magnetic properties of the VINCY iron

Special attention has been paid to the design of the magnetic structure. The acceleration of D^- ions up to 30 MeV per nucleon is chosen to be the nominal operating point of the cyclotron. In that case, the isochronous field should be produced by means of iron only. There are then pairs of circular trim coils to enable other regimes. To enlarge the number of other regimes, however, it is highly desirable to reduce the maximum deviation from the isochoronous field, especially in the case of low level magnet excitation (acceleration of 60 MeV protons).

To achieve the above goals, an extensive series of calculations has been carried out [3,4]. To avoid the restrictions of 2D methods, the calculations were iteratively coupled with model magnet measurements [5]. To do that, the model magnet of the Flerov Laboratory of Nuclear Reactions, JINR, Dubna, has been suited to the VINCY Cyclotron magnet in the scale 1:10.

Two kinds of sector shims, axial and azimuthal shim, have been subject of numerical and experimental simulation. As shown in the companion paper [5], the nominal isochronous field was achieved in both cases.

The axial shim has two advantages: (a) the central plug can be easily designed with a sufficiently large axial opening, and (b) the central harmonic coils can be located near to the median plane in the space where the sector material has been taken out. However, a very large deviation from the isochronous field can be observed (Figure 2) in the case of low level magnet excitation.

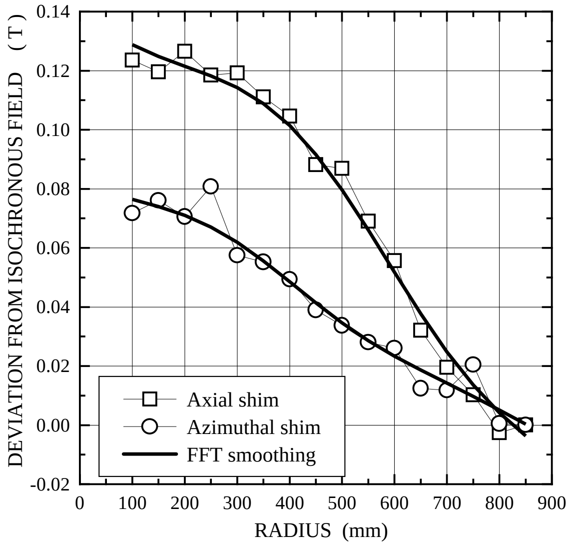

Figure 2. Deviation from isochronous field according to model magnet measurements for low level magnet excitation

The situation is just opposite in the case of azimuthal shim. The maximum deviation is twice smaller, but there are quite some troubles to design the magnetic plug and to get enough space for the central harmonic coils.

Therefore, a compromise solution is adopted for the VINCY Cyclotron. The sector thickness is partially reduced from the opposite side of the sector (the side towards the pole plate) in order to place the central harmonic coil. The rest of the necessary field correction should be done by the azimuthal shim. Both profiles are shown in Figure 3. According to experimental data, an intermediate deviation between the two extreme cases that are shown in Figure 2 is expected in the case of low level magnet excitation.

To resolve the problems in the central region, the plug is divided into two parts. The inner part is movable, while the outer one is fixed to the sectors and the median pole plate. The inflector is fixed to the inner part and both of them can be moved through the axial channel.

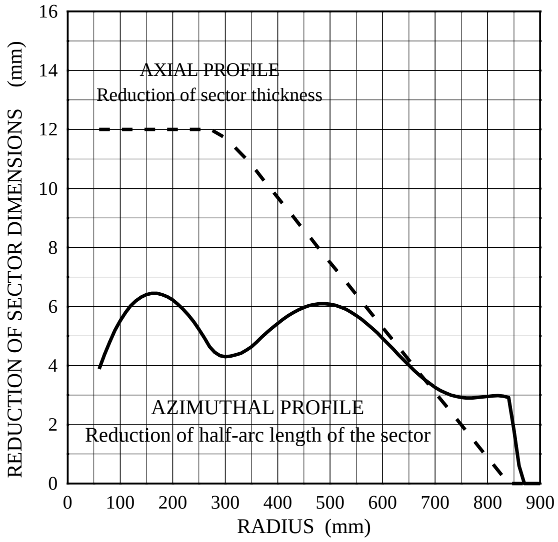

Figure 3. Axial and azimuthal profiles of the sectors

The magnetic field sensitivity to variation of sector dimensions is crucial in machining the ferromagnetic elements. Figure 4 shows the diminution of magnetic field as a function of the decrease of characteristic sector dimensions (thickness or half-arc length of the sector). For the axial shim, a machining accuracy of ±5 hundredths of millimeter is necessary to get a field accuracy of ±0.5 mT. The situation is much better in the case of azimuthal shim. Far from the center, the sensitivity is one order of magnitude lower. To decrease the sensitivity in the central region, a part of the sector tips is joined to the outer part of the plug.

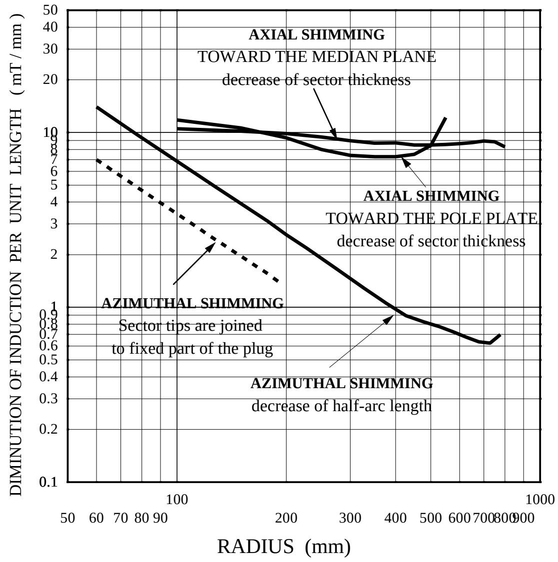

Figure 4. Sensitivity of magnetic field as a function of sector dimensions

3 OPERATING RANGE

Figure 5 presents the operating range of the VINCY Cyclotron as expected according to the numerical and experimental simulation. B_{iso} is the magnetic induction in the center of the machine, and *T/A* is the energy per nucleon of the ions at the extraction radius. The oblique lines represent the lines of constant specific charge of the ions. The rectangular regions show the range of the RF frequency (17-31 MHz). In the first rectangle the orbital frequency of the ions is equal to the RF frequency. In the second and the third rectangles, the orbital frequency is twice and four times smaller, respectively, than the frequency of the RF system. This is due to the fact that the inflector and the electrodes of the RF system are designed to accelerate ions on the 1st, 2nd and 4th harmonic numbers.

The magnetic properties of the machine determine the right, upper and left borders of the operating range. The bending constant (right border) is 145 MeV. The focusing constant (upper border) is 75 MeV. The left border is due to the maximal current of the trim coils.

To illustrate the multipurpose character of the machine, Figure 6 presents its operating range in terms of ion beams. A number of beams (Table 1) is shown according to the proposed user programs.

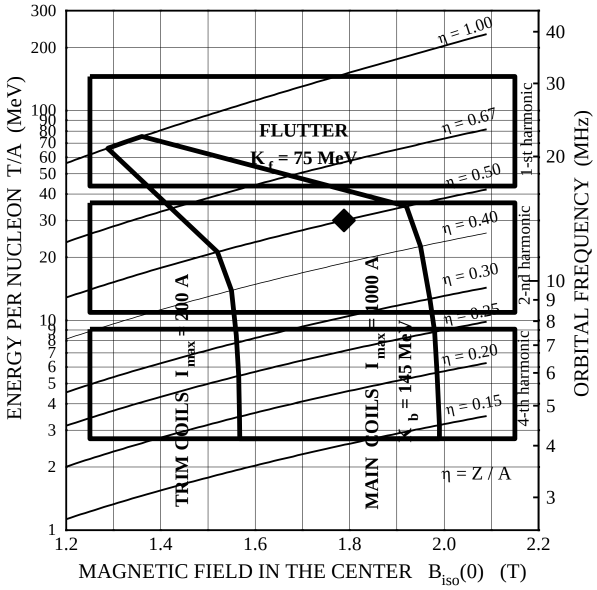

Figure 5. Operating range of the VINCY Cyclotron in terms of cyclotron parameters

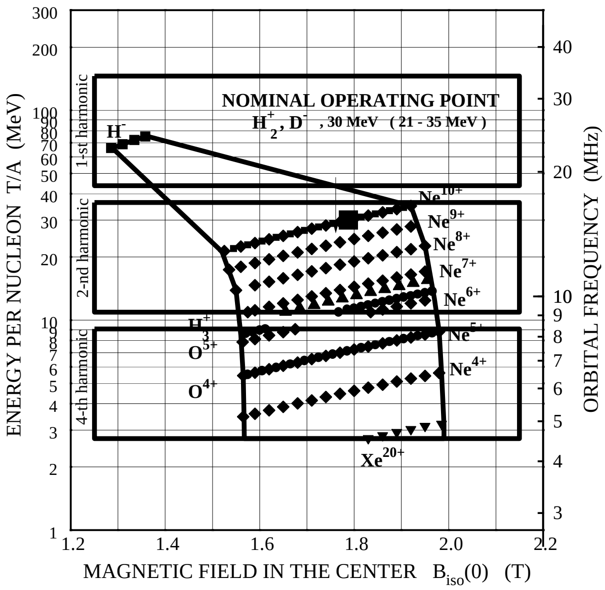

Figure 6. Operating range of the VINCY Cyclotron in terms of selected ion beams

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