UPGRADE OF IBA CYCLONE® 3 CYCLOTRON

W. Kleeven, M. Abs, E. Forton, D. Neuveglise, S. Zaremba, B. Nactergal and Th. Servais
Ion Beam Applications s.a., Chemin du Cyclotron 3, Louvain-la-Neuve, Belgium

Abstract

Some specific applications of $^{15}O_2$ need a stand alone production machine to avoid disrupting the hospital main PET cyclotron. Due to recent renewal in interest, IBA has decided to improve the design of its Cyclone® 3 which accelerates D^+ ions to energy of more than 3 MeV and which was originally developed for this purpose.

The main improvement relates to the magnetic structure. In the existing design the vertical focusing is obtained by four straight pole-sectors that are mounted on the circular base of the pole. In the new design these are replaced by three spiralled pole sectors. This modification changes the rotational symmetry from four to three and improves the vertical focusing properties of the machine. Also the main coil and the return yoke were slightly modified. This allowed increasing the extraction energy by about 10 % from 3.3 MeV to 3.6 MeV.

This new design will improve the transmission in the cyclotron and will result in an extraction efficiency of more than 80% using an electrostatic deflector. For the prototype the goal is to obtain an extracted current of 50 µA. This value should rise to 70 µA for subsequent machines, representing a doubling of the existing performance.

In the paper, results of magnetic field optimization and extraction calculations are presented.

INTRODUCTION

The Cyclone® 3 has been developed in the early nineties [1-6] as a very compact cyclotron for stand alone production of Oxygen-15 in open flow. Even if still in use, only few machines have been sold. Recently, new markets have shown more interest in the Cyclone® 3 concept. An example is the promotion of new emergency-room evaluation of brain stroke and ischemic attack in remote centres.

As a consequence, IBA decided to review its Cyclone® 3 design and improve it. This paper describes the modifications made on the magnetic circuit of the cyclotron to improve its expected performances.

MAGNET FEATURES

In its first version, the Cyclone® 3 had 4 magnetic poles (fig. 1). That choice was rather natural to avoid impedance imbalance between the two RF cavities. The Cyclone® 3 is equipped with two 90 degrees dees. However, such design had two major drawbacks:

1. Due to the hill-valley small gap difference, the flutter was relatively low and vertical (axial) betatron frequency was about 0.15. This ensures the minimal axial focusing but is far from the axial focusing provided by IBA patented deep valley design.
2. Due to the size of the machine and available space between poles there was very limited place for the electrostatic deflector.

IBA took some distance with its habit to have four-fold rotational symmetry cyclotrons and proposed a new design with only 3 poles that are spiralled to increase the axial betatron oscillation frequency. This new design has the additional advantage to leave more room for the extraction system. The schematic view of the new magnet is shown on figure 2.

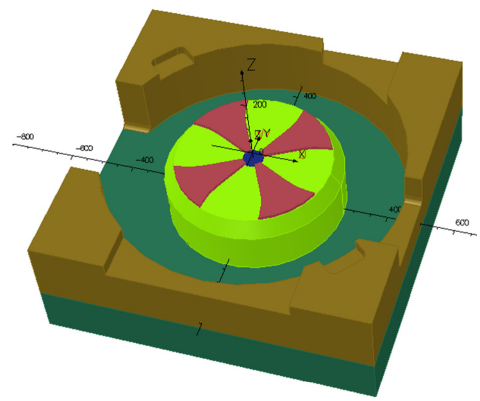

Figure 1: Previous design of the Cyclone® 3 (coils not shown).

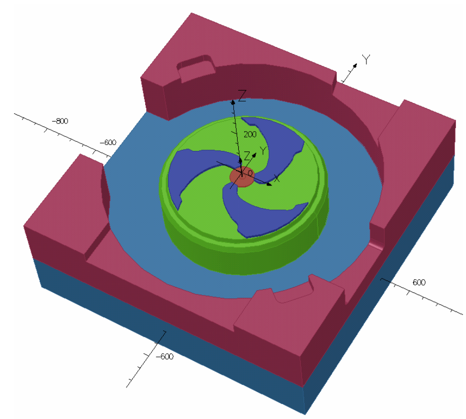

Figure 2: New design of the Cyclone® 3 (coils not shown).

It is also worth to mention that the outer contour of the cyclotron yoke has been modified to limit iron saturation effects.

CLOSED ORBIT ANALYSIS

The OPERA models have first been used to obtain a nominal configuration that is isochronous and shows reasonable frequencies of betatron oscillations.

After a classical correction of the field in the hard-edge approximation, the model proved to be isochronous with the (second harmonic mode) RF frequency of 28.805 MHz (fig. 3). Closed orbits have been found up to an energy of 3.94 MeV.

The vertical (axial) betatron oscillation frequency (fig. 4) has been raised. A compromise on the spiral angle as a function of radius has been found in order to achieve that increase in axial betatron frequency while keeping the advantage of 3-fold rotational pole symmetry for deflector space. At an average radius of 15 cm, it is now about 0.21, to be compared with values around 0.17 for the previous design.

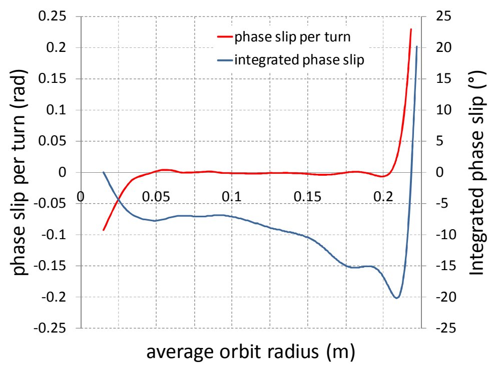

Figure 3: Isochronism of the Cyclone® 3 model.

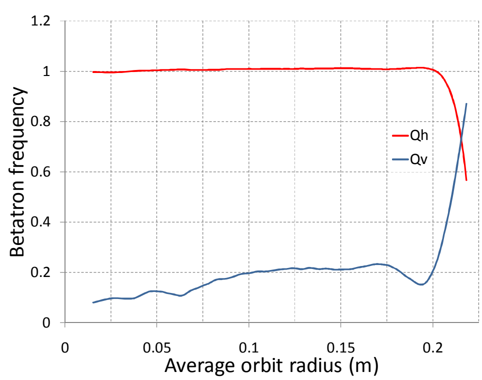

Figure 4: Horizontal and vertical (axial) betatron frequencies as a function of average orbit radius.

BEAM ACCELERATION AND EXTRACTION

The beam extraction has been studied by particle tracking, starting from the equilibrium orbit with kinetic energy of 1 MeV. Normalized horizontal and vertical emittances have been chosen to be 3π mm·mrad.

The electrostatic deflector has an entrance gap of 4 mm, an exit gap of 8 mm. It was modelled by the change of the magnetic field being the equivalent of the electric field in the deflector when the tracked particle reaches a given radius and azimuth.

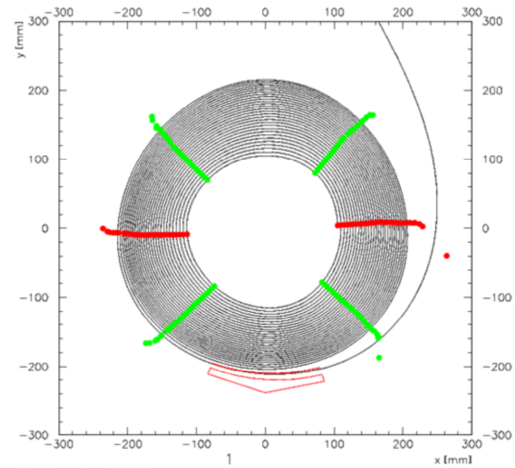

Figure 5: Single particle trajectory showing acceleration and extraction by the electrostatic deflector. 3-Fold symmetry and effect of the pole spiralization can be observed in the turn pattern.

Figure 5 shows an example of the particle trajectory from kinetic energy 1 MeV to extraction. Red and green dotted curves correspond to trajectory points where the dee voltage was 0 and 30 kV dee voltage, respectively. These dotted curves confirm the correct isochronism of the magnetic field.

At 3.5 MeV, the extraction radius is 202 mm and the deflector has an extraction efficiency of 87.8 %. 53.1 % of the total beam reaches the internal target.

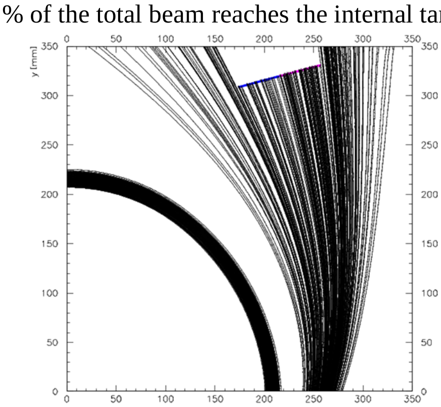

Figure 6: Multiple particle tracking for determination of efficiency on internal target.

Figure 6 presents last few turns of calculated trajectories for 500 tracked D^+ ions. In the region of the internal target one can see the important horizontal extension of the beam related to the passage by the fringing field of the cyclotron.

This could be improved by correcting optics between the deflector and the target, using for instance 3-bar correctors. It is difficult due to the present dee and vacuum chamber design which limits available space and would need modifications to accommodate for such elements.

PRESENT STATUS

All iron parts of the newly designed magnet have been already machined. The magnet iron was assembled and is ready in IBA assembly hall for magnetic field measurements.

Figure 7: Cyclone® 3 being currently assembled at the Belgian IBA facility. One can distinguish the various vacuum chamber access in the return yoke: pumping and dee stems access (top), the deflector access (left) and the target hole (bottom).

CONCLUSIONS

This new development was unique at IBA due to the fact that for the first time the three-fold rotational symmetry was applied. This successfully contributed to increase of the modest vertical (axial) focusing in Cyclone® 3 cyclotron. The new design also increased the kinetic energy of extracted ions keeping the same pole diameter as before. This will boost production yield of Oxygen-15, especially at this energy range, where the production yield is rapidly going up.

REFERENCES

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