Extraction system design for the new IBA cyclotron for PET radioisotope production

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ABSTRACT

IBA, has constructed, tested and industrialized an innovative isochronous cyclotron for PET isotope production [1,2]. The design is compact and optimized for low cost, easy maintenance and high performances, with a particular emphasis on its application and market. Multiple target stations can be placed around the vacuum chamber. An innovative extraction method (patent applications pending) allows to obtain the same extracted beam sizes and properties on the target window independent of the target number. This is achieved by proper design and shaping of the magnet poles. Extraction/magnetic design, beam simulations and first commissioning results are discussed

EXTRACTION DESIGN

- Stripping extraction of H^-
- 4-fold symmetry
- 8 beam-ports (2 stripper foils on each pole)
- Dual beam extraction capability
- Design goals
  - **Roughly same beam spot on all targets** ⇒ pole radial contour is off-centred circle following shape of 18 MeV closed orbit
  - **Roughly round beam spot on target** ⇒ optimized iron cut at radial pole edge exit point, to adjust the vertical focusing

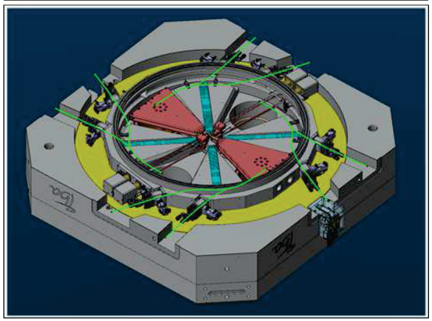

Figure 1: Upper half of the CYCLONE®KIUBE. In grey is shown the magnetic iron including the return yoke and the four poles. Pole-inserts (in blue) are used to shim the isochronous field. Further shown is the main coil (yellow), the accelerating structure (red) and the 8 target stations mounted on the vacuum chamber. Extracted orbits are shown in green.

SIMULATIONS

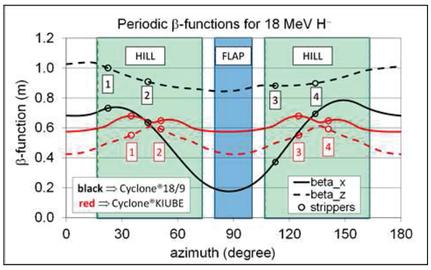

Figure 2: Periodic β-functions along the 18 MeV closed orbit. The red curves correspond with the CYCLONE®KIUBE. For comparison, the same curves are given for the CYCLONE®18/9

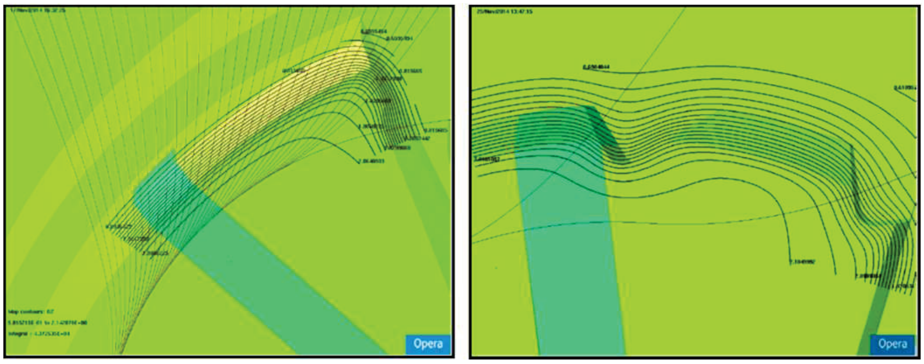

Figure 3: Iso-field lines are shown on top of the OPEAR3D model in the region of the pole radial boundary. Also shown are trajectories of a series of particles extracted at various angular positions of the stripping foil. The left figure shows that there is a rather large angle between the particle direction and the normal vector of the field-lines. This condition leads to a rather large vertical defocusing. The figure on the right shows the modification of the magnetic field pattern due to the iron cuts placed at the pole exit azimuth of the particles. Here the vertical defocusing is much weaker.

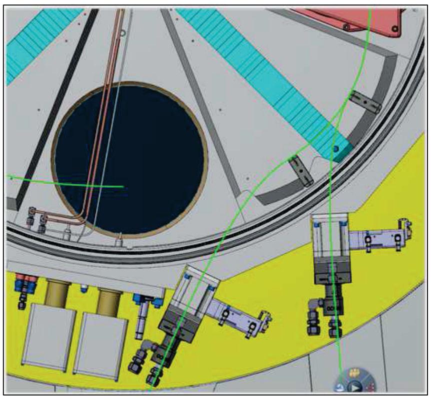

Figure 4: The radial pole contour is (a part of) an off-centred circle which closely follows the shape of the closed orbits near extraction. The pole cuts are shown and also the stripper carousels and the extracted orbits (in green) hitting the isotope production targets.

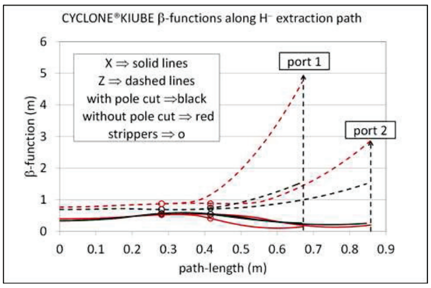

Figure 5: β-functions along the extraction path. Comparison configurations with and without pole cuts. Stripper positions are also shown.

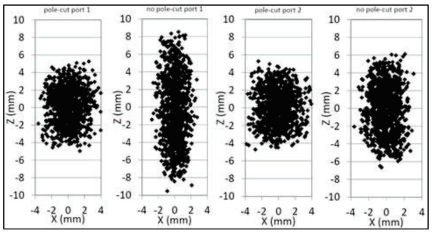

Figure 7: Beam spots on targets as simulated with AOC. A more symmetric (round) shape is obtained due to the pole cuts. The spots on both extraction ports are almost the same.

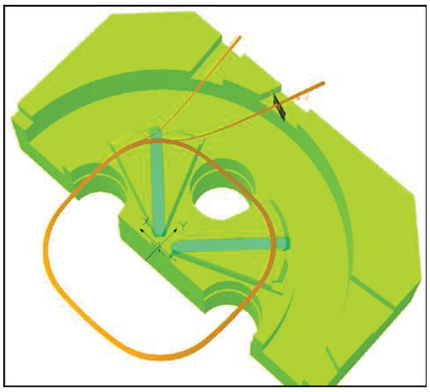

Figure 6: Orbits are numerically integrated with the IBA in-house tracking code AOC [3] and imported into the finite element model of the CYCLONE®KIUBE magnet as developed in OPERA3D. Two stripper foils placed on one pole extract the beam towards the corresponding targets. The beam spot and phase space is analyzed on a patch, placed at the target entrance window.

CYCLOTRON COMMISSIONING

The prototype of the CYCLONE®KIUBE has been successfully commissioned at the IBA-sites in Louvain-La-Neuve and is currently being installed on the customer site. The performance of the machine well exceeds the CYCLONE®18/9 in terms of beam transmission between the ion source and the stripper foils, the extraction efficiency between the strippers and the targets and also in terms of the 18-F production yields. The extraction efficiency (defined as the ratio between target current and target + collimator current) is for all 8 target positions, between 90 and 95% for a collimator diameter of 9 mm.

[1] E. Kral *et al.*, "Development of a new IBA cyclotron for PET production", this conference, TUD03.
[2] S. Zaremba *et al.*, "Magnet design of the new IBA cyclotron for PET radioisotope production", this conference, TUP04.
[3] W. Kleeven *et al.*, "AOC, a beam dynamics design code for medical and industrial accelerators at IBA", in *Proc. 7th Int. Part. Acc. Conf.*, Busan, Korea, 2016,pp. 1902-1904.

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